REMARKS

Objections to the Claims

The Office Action objects to the claims since the numbering of claims does not comply with 37 CFR 1.126. The Office Action indicates that misnumbered claims 13-16 have been renumbered as claims 12-15, but that the original claim numbering was maintained in the current office action. Applicant's listing of claims incorporates the renumbering.

Amendments to the Claims

Claims 1 and 8-15 are under examination with entry of the present Amendment. Claim 15 has been amended to correct the claim dependency. New claims 16, 17 and 18 are newly added.

New claim 16 is drawn to a processed, ready-to-eat food item suitable for consumption by healthy humans comprising a protein source, a fat source and a carbohydrate source, wherein the total carbohydrate content of the food item is greater than about 45% by weight, and the glycemic index of the food item is lower than 50 (71) as calculated as an area under the curve on a blood glucose graph over time. Support resides in the as-filed specification for example, in paragraph [0021].

New claim 17 is drawn to a method of sustaining blood glucose levels in healthy humans by administering the food item of claim 16. Support resides in the as-filed specification for example, in paragraphs [0012] and [0017].

New claim 18 is drawn to a processed, ready-to-eat food item comprising a protein source, a fat source, a carbohydrate source, and a fiber source, the protein source containing a blend of soy, whey, calcium caseinate, almonds and barley, the fat source containing a blend of almonds, soybeans and barley, the carbohydrate source containing a blend of pureed plums, fructose, barley flakes, soy nuts, cherries and inulin, and the fiber source containing a blend of inulin, soybeans, almonds, pureed plums, cherries and barley, wherein the total carbohydrate content of the food item is greater

than about 45% by weight, and the glycemic index of the food item is lower than 50 (71). Support resides in the as-filed specification for example, in paragraphs [0022] to [0034] and paragraphs [0038] to [0063].

No new matter has been added with the amendments made herein. Support for the amended and new claims is found throughout the application and in the as-filed claims. Applicants believe that the amended and new claims better define the invention in a manner supported by the original application, and in a manner so as to render moot the rejections as set out in greater detail below.

Rejections under 35 U.S.C. §103

The Office Action rejects claims 1, 10, 11 and 15 as being unpatentable over U.S. Patent No. 5,776,887 to Wibert *et al.* The Office Action states that Wibert *et al.* discloses a composition containing the claimed ingredients as in claims 1, 10, 11 and 15:

> The carbohydrate content is seen to have been more than 50% as in claims 1, 10 and 11 because rolled oats, which are a complex carbohydrate with a low GI is used in predominant amounts and the reference discloses 62% carbohydrates (col. 8, lines 40-60). Also, the GI is seen to have been within the claimed amounts of 1, 10, 11 and 15, due to the use of complex carbohydrates absent a showing to the contrary. Therefore, it would have been obvious to use known ingredients and known amounts of COH and a GI absent a showing to the contrary.

Applicants respectfully traverse this rejection. Applicants submit that a proper obviousness rejection has not been made. Section 706.02(j) of the USPTO Manual of Patent Examining Procedure states:

> To establish a *prima facie* case of obviousness, three basic criteria must be met. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all the claim limitations. The teaching or suggestion to make the claimed combination and the reasonable expectation of success must both be found in the prior art and not based on applicant's disclosure. *In re Vaeck,* 947 F.2d 488, 20 USPQ2d 1438 (Fed. Cir. 1991).

Applicants submit that Wibert *et al.* addresses a different problem. Wibert *et al.* provides a composition for controlling or sustaining absorption of carbohydrates during digestion by diabetics, thereby avoiding excessive blood glucose peaks. This is not pertinent to the problem with which Applicants were concerned, namely a food item having the dual benefits of a high carbohydrate fraction and a low glycemic index, and intended as a snack bar for healthy individuals for sustaining blood glucose levels throughout the day. It is significant to differentiate the influence food intake has in relation to normal subjects versus subjects with pathological disorders such as diabetes. The Wibert product is specifically targeted at diabetics. Applicants' food item is intended for any healthy person who wishes to have a processed, ready-to-eat food item with a low glycemic index. Persons with diabetes can take much longer to dispose of the postprandial glucose versus normal subjects and may require much longer for their blood glucose to return to normal concentrations, if at all (Pi-Sunyer, 2002). The low glycemic bar of the present invention is designed primarily for normal, healthy populations with the objective of using it as a snack bar to sustain blood glucose levels in normal, healthy subjects throughout the day. In contrast, the Wibert patent describes a "nutritional composition for use by diabetics which results in a controlled or sustained absorption of carbohydrate during digestion". As the suggestion to modify or combine must be found within the reference itself, Applicants respectfully submit that a *prima facie* case for obviousness has not been made.

Wibert *et al.*'s composition comprises a balanced mix of carbohydrate fractions including a rapidly absorbed fraction such as sucrose, a moderately absorbed fraction such as mannose or fructose, and a slowly absorbed fraction such as raw corn starch. Wibert *et al.* is not concerned with low glycemic index of the complete composition, as evidenced by the inclusion of, for example, sucrose which has a very high glycemic index. Sucrose used in the composition by Wibert *et al.* to boost blood glucose levels would be an incompatible and undesirable ingredient in the food item claimed by Applicants. Wibert *et al.* thus teaches away from a low glycemic index composition, making no suggestion or mention of the importance of a low glycemic index of the complete composition or the advantages of same, as disclosed by Applicants. Wibert *et al.* does not provide a

suggestion of any success in modifying the reference teachings to arrive at Applicants' claimed invention.

To establish a *prima facie* case for obviousness, the prior art reference must also teach or suggest all the claim limitations. Applicants disagree with the Examiner's comments that "rolled oats which are a complex carbohydrate with a low GI is used in predominant amounts" and "the GI is seen to have been within the claimed amounts of 1, 10, 11 and 15, due to the use of complex carbohydrates absent a showing to the contrary." With reference to the claim language, Applicants submit that Wibert *et al.* does not teach or suggest a complete food item having a glycemic index lower than 50(71), as explicitly recited in Applicants' claim 1. Claim 1 distinctly recites "the glycemic index of the food item" to clarify that the glycemic index pertains to the complete food item, not to individual ingredients of which the food item is composed. The Examiner's comment pertains to a single ingredient (rolled oats) included in an amount which allegedly renders a low glycemic index for Wibert *et al.*'s composition. Applicants emphasize that the glycemic index numbers of each ingredient contained in a product cannot be simply added together, or a large amount of a single ingredient allegedly having a low glycemic index cannot be used to determine or predict the glycemic index of the product as a whole. As set out in Applicants' submission of December 29, 2006, several variables (not reiterated in this response) can affect the final GI value of a product in relation to the individual ingredients being combined together to make the final product. It is thus necessary to measure the area under the curve in comparison with a standard selected from glucose or white bread using validated protocols to obtain an accurate measure of the final glycemic index of a product. This is further emphasized by the results of an inter-laboratory study conducted in 2003 which utilized the same testing method which was used to test the Applicants' food item. The results of the study further emphasize the need for standardized testing methods. Without such methods, the variation in GI values obtained can be significant and therefore, not reputable or representative of the food item. The results also explained that there can be wide variations in GI values even when the same testing method is used, but when the protocol is not tightly adhered to - again, emphasizing the importance of having the testing done by a reputable laboratory who is skilled in the art of GI testing.

Applicants' food item was tested by Glycaemic Index Testing Inc. in Toronto to obtain an accurate measure of the glycemic index, thereby providing support for the specific glycemic index recited in claim 1. The protocol for the testing method used is recognized as the standard to those skilled in the art and was originally described by an Expert WHO (World Health Organization) Consultation Committee on Carbohydrates 1997 (Carbohydrates in Human Nutrition FAO Food and Nutrition Paper; Wolever *et al.* (2007) European Journal of Clinical Nutrition 57:475-482, attached). This protocol has been more recently adopted as a standard by Standards Australia (January 2007) in an effort to improve the accuracy and reliability of GI values on food products. A national standard, prepared by an independent body like Standards Australia, provides an alternative to using different in-house methods to obtain the GI value of a food. Also, by having the testing method as a standard, this sets out a recognized scientific method to determine the GI of foods and has also been submitted to the International Organization for Standardization (ISO) for possible adoption by member countries around the world including Canada, China, France, India, Japan, Malaysia, South Africa, the UK and US.

Wibert *et al.* does not teach that a glycemic index lower than 50(71) is desirable or results in beneficial properties for a food item. Even if one were to read such a suggestion in Wibert *et al.*, there is no teaching directing how low the glycemic index should be or to what degree, if any, this will improve the properties of the food item. Wilbert *et al.* thus does not itself suggest of any motivation or combination, nor of any reasonable likelihood of success, as required for an obviousness rejection. Reconsideration and withdrawal of this rejection are thus respectfully requested.

The Office Action rejects claims 1, 8, 10 and 11 as being unpatentable over U.S. Patent No. 6,458,378 to Sunvold. The Office Action states that Sunvold discloses a composition as in claim 1 for improving glucose metabolism in animals by controlling the insulin response, which contains a source of protein, fat and carbohydrates. The Office Action states that:

> The carbohydrates in the food item are greater than 45% by weight. Grains are not considered to be rapidly absorbed carbohydrates, since they contain a lot of fiber, which

keeps the carbohydrates from being rapidly absorbed (col. 8, lines 35-60). Claims 1, 8, 10 and 11 differ from the reference in the particular glycemic index (GI). Sunvold discloses the use of a composition containing grains, which is seen to have produced a composition with a GI lower than 50 since grains are used in the composition and no simple sugars or sucrose. Therefore, it would have been obvious to make a composition using the claimed ingredients.

Applicants respectfully traverse this rejection. Applicants submit that Sunvold is not analogous prior art. In order to rely on a reference as a basis for rejection of an applicant's invention, the reference must either be in the field of applicant's endeavour or, if not, then be reasonably pertinent to the particular problem with which the inventor was concerned. Sunvold relates to a pet food composition including a protein source, a fat source and a carbohydrate source based on multiple grains to improve glucose and insulin metabolism in companion animals, for example, dogs and cats. In contrast, Applicants' food item is intended for human consumption. The digestive systems and nutritional requirements for humans and companion animals are vastly different (see, for example, Bicks, "Nutritional Differences Between Dogs and Humans," attached). One skilled in the art would thus not be motivated to modify or combine the teachings of Sunvold related to a pet composition to arrive at Applicants' claimed food item for humans. Since pet compositions generally contain ingredients unfit for human consumption, there would be no reasonable expectation of success in using the Sunvold reference to arrive at Applicants' claimed food item.

Even if Sunvold's composition were to be suitable for humans, Applicants note that Sunvold fails to teach or suggest all Applicants' claim limitations, as required for an obviousness rejection. The Examiner comments that a single ingredient (grains) of the Sunvold composition "is seen to have produced a composition with a GI lower than 50." As previously discussed, Applicants emphasize that a large amount of a single ingredient allegedly having a low glycemic index cannot be used to determine or predict the glycemic index of the product as a whole. The Examiner even admits of a difference, stating that "claims 1, 8, 10 and 11 differ from the reference in the particular glycemic index (GI)." Sunvold does not teach or suggest a complete food item having a glycemic index lower than 50(71), as explicitly recited in Applicants' claim 1. The language of Applicants' claim 1 thus distinguishes the teachings of Sunvold. Reconsideration and withdrawal of this rejection are respectfully requested.

The Office Action rejects claims 9 and 15 as being unpatentable over Sunvold as applied to the above claims, and further in view of Wibert *et al.* The Office Action states that claim 9 further requires that the composition contains inulin, but not a starch. However, Wibert *et al.* discloses that it is known to use inulin in a diet, which controls the GI (col. 3, lines 50-59). Therefore, it would have been obvious to use a known source of fiber in the composition of Sunvold for its known function.

Applicants respectfully traverse this rejection. Applicants submit that there is no motivation to combine the references. Obviousness can be established only by combining or modifying the teachings of the prior art to produce the claimed invention where there is some teaching, suggestion or motivation to do so found either explicitly or implicitly in the references themselves or in the knowledge generally available to one of ordinary skill in the art. Even if one of ordinary skill in the art did consider the references chosen by the Examiner, the references themselves do not provide a suggestion of any success in combining the reference teachings to arrive at Applicants' claimed invention.

The Office Action has combined the teachings of Sunvold with those of Wibert *et al.* The Office Action turns to Wibert *et al.* for teachings of inulin. The additional cited reference does nothing to overcome the deficiencies of Sunvold, nor is there a suggestion in either reference to combine the references. The Office Action relies upon a one line statement in Wibert *et al.* as evidence that inulin in accordance with Applicants' claimed food item is suggested. Although Wibert *et al.* provides a broad list of fiber sources, there is no teaching that any particular fiber source should be used in Sunvold's composition or that it would yield Applicants' food item. Wibert *et al.* simply mentions that the "fibers and non-absorbant carbohydrates have a glycemic index less than 2;" however, nowhere does the passage teach or suggest that inulin "controls GI" as alleged by the Office Action. As previously discussed, Applicants emphasize that a single ingredient cannot be used to determine or predict the glycemic index of the product as a whole. Thus, the combination does not teach or suggest Applicants' claimed subject matter. Reconsideration and withdrawal of this rejection are thus respectfully requested.

The Office Action rejects claim 1, 10, 11, 13 and 14 as being unpatentable over Nidetch (Weight Watchers, pages 218-219). The Office Action states that Nidetch discloses a composition containing protein, fat and carbohydrates where the total carbohydrate content is more than 45% as in claims 1 and 10:

> Casein is the major protein found in cheddar cheese and skim milk as in claim 14. The claims differ from the reference as to the particular GI. However, the GI is seen to have been less than 40 as in claims 1, 10, 11 and 14 and less than 35, as in claim 13 since the composition has been shown (pages 218-219). Therefore, it would have been obvious to make a composition containing the claimed ingredients and glycemic index.

Applicants respectfully traverse this rejection. Applicants submit that Nidetch simply provides a single recipe for cheddar muffins. Claim 14, which recites casein as a protein source, depends upon claim 1 which is believed to patentably distinguish the cited prior art as previously discussed. The Examiner comments that a single ingredient (casein from the cheddar cheese and skin milk) of the Nidetch recipe "is seen to have produced a composition with a GI lower than 40." As previously discussed, Applicants emphasize that a single ingredient cannot be used to determine or predict the glycemic index of the product as a whole. The Examiner even admits of a difference, stating that "the claims differ from the reference in the particular glycemic index (GI)." Nidetch does not teach or suggest a complete food item having a glycemic index lower than 50(71), as explicitly recited in Applicants' claim 1. The language of Applicants' claim 1 (and dependent claims 10, 11, 13 and 14) thus distinguishes the teachings of Nidetch. Reconsideration and withdrawal of this rejection are respectfully requested.

The Office Action rejects claim 16 as being unpatentable over Sunvold in view of Wibert *et al.* and further in view of Foster-Power International Table of Glycemic Index. The Office Action states that:

> claim 16 further requires that the composition is a food item with particular amounts of ingredients. However, it is seen that it would have been within the skill of the ordinary worker to determine the amounts of carbohydrate and the glycemic index of various foods and to make a composition with known ingredients which was within the claimed limitations, especially as Applicants have provided in their Information Disclosure Statement a table of

Foods which shows the glycemic index of various foods. Painter discloses the value of using the GI to determine which foods would have been desirable for people and that "an energy bar could be designed with COH's that provide a low glycemic response using fructose and that the GI can be accurately estimated from food (page 4, 1 col., 2nd paragraph, page 7, first paragraph, col. 2). Therefore, it would have been obvious to choose various foods with known amounts of carbohydrate and a known glycemic index in which to make a food composition.

Applicants respectfully traverse this rejection. Applicants submit that the prior art has attempted to achieve low glycemic index by formulating low carbohydrate products. For example, the Body Wise® Lean Index™ Bar by Body Wise International Inc. advertises a glycemic index of 38 but has a carbohydrate content of only 40% by weight, with protein at 40% and fat at 20%. Like other nutritional bars, it is an attempt to provide a "balanced" composition of nutrients in a high protein diet. Another example is the Balance® Bar which advertises a 40-30-30 ratio of protein, carbohydrate and fat respectively, on a caloric basis. The Balance® Bar contains 44% carbohydrates on a weight basis and has a low glycemic index of less than about 50. The NuGo Nutrition™ bar has more than 50% carbohydrate but was able to achieve a GI of only about 50. Applicants are persons highly skilled in this art, specializing in research of functional foods. To Applicants' knowledge, the prior art bars, for example, the Balance® Bar, is based on the 40-30-30 principle, a nutritional philosophy popularized by Dr. Barry Sears with the intention of providing sustained energy and hunger management. The Balance® Bar is advertised as a "nutrition and energy bar to keep you going" on the Balance® Bar website (http://www.balance.com/original/default.aspx). The formulation of the Balance® Bar thus originates from a known principle or ratio (40-30-30). Unlike the prior art bars, Applicants' food item was not based on a known principle or simple recipe of assorted ingredients. Rather, Applicants' objective from the start was to develop a food item "from scratch" scientifically formulated to have a low glycemic index and contain predominantly natural ingredients. To Applicants' knowledge, no prior art has recognized that a low glycemic index can be provided without unduly reducing the carbohydrate or nutritional content of the food item, as achieved by Applicants.

As set out in the Affidavit submitted December 29, 2006, considerable inventive effort was required in order to arrive at Applicants' claimed food item, and explains why it was not obvious to

those skilled in the art to formulate such a product. As Applicants have emphasized, the glycemic index is not readily predictable from its composition. The glycemic index numbers of each ingredient contained in a product cannot be simply added together, or a large amount of a single ingredient allegedly having a low glycemic index cannot be used to determine or predict the glycemic index of the product as a whole. The development of Applicants' food item involved different formulations, variations and testing to achieve the desired properties of high carbohydrate content and low glycemic index (see for example, Exhibit "D" of the Affidavit comprising excerpts from a laboratory notebook). The culmination of many years of scientific research and testing led to the development of Applicants' food item as summarized below and detailed in the Affidavit submitted December 29, 2006:

1. Applicants had spoken to Dr. Wolever of the Glycaemic Index Testing Inc. about testing the glycemic index of Applicants' nutritional bar formulations (confirmed by letter addressed to Saul Katz from Dr. Wolever dated 17 February 2000).

2. Two of Applicants' formulations (which were in existence prior to 17 February 2000) were provided to Dr. Wolever. Applicants had discussions with GIT by that date regarding testing of bars Applicants had developed which were believed to be high carbohydrate, low glycemic index bars. Applicants worked with Dr. Wolever with different formulations and variations of such bars and continued development of the product from that time forward. One embodiment, which Applicants had referred to as a Lemon Bar, finished testing in May 2001.

3. The general formulation of the Lemon Bar was conceived of prior to 17 February 2000.

4. Exhibit "D" of the Affidavit (excerpts from a laboratory notebook) traces the scientific research and testing, including the following developments:

(a) Applicants conceived of a low GI, high carbohydrate product incorporating soluble fiber, unsaturated fats, and a moderate amount of protein (page 3 of the notebook);

(b) on February 18, 2000, a bar containing a fructose-based binder, fruit pieces and inulin fiber, having 28.97g of carbohydrates ("carbo") in a 50 g bar was tested. One subject ("Huy") showed a GI of 41 (page 21 of the notebook);

(c) on page 22, a modification was made to one formulation to increase plum puree, was found to "mix OK" (February 22);

(d) many different ingredients were tested during this time, many of which are found in the formulation described in embodiments of the present patent application;

(e) on March 1, a combination having 28.04 g carbo / 50 g bar, resulting in a GI average between 2 subjects of 51 was achieved;

(f) on March 2, calcium caseinate, glycerine and inulin IQ were added;

(g) on March 7, the ingredient "energy smart" which was a fructose-based mid-GI binder and sweetener was replaced with fructose; and

(h) on March 8, Applicants were able to achieve low GI values averaging in the mid-20's with a 50g bar having 28.61 g of carbohydrates (page 41 of the notebook)

During development of the food item, Applicants needed to consider additional important factors including, for example, particle size, fiber content, monosaccharide and disaccharide profile, palatability, functionality, organoleptic profile (taste, texture, aroma, visual appeal), and moisture content (affects the shelf life).

With respect to Claim 16, Applicants submit that the protein, fat and carbohydrate sources were chosen and derived from a specific blend and combination of ingredients to achieve a very specialized nutritional and low glycemic food item. Each ingredient was also chosen for its contribution to the protein (including the amino acid profile), fat (including the fatty acid profile), as well as the carbohydrate (including the monosaccharide and disaccharide fractions) content in the food item. Many of the ingredients provide a balance of all three of these macronutrients. Each ingredient provides nutritional and health benefits and in some cases, also creates synergisms with

other ingredients within the blend to provide nutritional and physiological benefits for healthy populations as summarized below:

Combinations of ingredients and their benefits:

a) Protein: Combining protein sources from soy, whey, calcium caseinate, almonds and barley to provide nutritionally complete protein with all of the essential and non-essential amino acids.

b) Fat: Combining fat sources from almonds, soybeans and barley to provide a range of heart-protecting sources of fats including monounsaturated and polyunsaturated fats, as well as essential fatty acids.

c) Carbohydrate: Combining carbohydrate sources from pureed plums, fructose from corn and agave, barley flakes, soy nuts, cherries and inulin.

d) Fiber: Combining sources from inulin, soybeans, almonds, plums, cherries and barley. The fiber portion contains approximately 20% insoluble fiber and 80% soluble fiber.

Individual ingredient benefits:

a) Almond butter: High in monounsaturated fats (linoleic and oleic acids). Linoleic is an essential fatty acid (the body cannot produce it and must be taken in by the diet). EFA's maintain the health of cell membranes, improve nutrient use, establish and control cellular metabolism, and help to lower serum cholesterol levels. Oleic acid has been linked to with a reduced risk for cardiovascular diseases and has also been shown to lower serum cholesterol levels. Almond butter is also rich in vitamin E and selenium, which are known for their antioxidant properties and help protect against cell damage. Almond Butter is also a good source of quality protein. This ingredient also provides mouthfeel and extends the shelf-life of the low GI bar.

b) Plum puree: The function in the bar is primarily for binding the dry ingredients, but the plum also provides naturally-derived carbohydrates and soluble fiber.

c) Dried cherries: Provides soluble fiber, beneficial antioxidants and naturally-derived carbohydrates.

d) Soy: In addition to providing quality protein, soy is also known to contain isoflavonoids which help to regulate hormone function in both men and women. It may also help to prevent heart disease by reducing total cholesterol, low density lipoprotein (LDL) cholesterol, blood pressure and possibly preventing plaque buildup in the arteries (atherosclerosis).

e) Whey protein: In addition to the quality protein, whey protein provides many peptides which may play a potentially significant biological role in the body.

f) Barley: Has known cholesterol-lowering properties similar to oats due to the beta-glucan (soluble fiber) content, which can assist in the reduction of coronary heart disease and diabetes. Barley also supplies whole grain which can also help with weight maintenance.

g) Inulin: Provides good quality soluble dietary fiber and is a probiotic which promotes the growth of functional/beneficial bacteria. Inulin has also been shown to play a role in the management of serum lipid and cholesterol levels, which are directly correlated with a reduced risk for cardiovascular disease.

The Office Action has combined the teachings of Sunvold with those of Wibert *et al.* and the Foster-Power International Table of Glycemic Index. Claim 16 is ultimately dependent on claim 1 which recites the glycemic index of the food item as lower than 50(71). The Office Action acknowledges that Sunvold does not teach the particular glycemic index, so there is certainly no indication of how low the glycemic index should be or to what degree, if any, this will improve the properties of the food item within Sunvold. None of the Wibert *et al.* or Foster-Power references

suggests the specific glycemic index of the complete food item recited in claim 1. The glycemic index testing on Applicants' food item was conducted in "normal" subjects as the food item was intended for normal, healthy individuals. In contrast, the Wibert *et al.* invention, although not actually tested clinically for the glycemic index value, *should* have been tested in diabetic individuals as this was the intended target market for the products. Diabetics have different physiological mechanisms for digesting and metabolizing carbohydrates from food, as compared to normal, healthy individuals. The normal individual is in a state of homeostasis with respect to blood sugar levels, whereas the diabetic individual has an impaired metabolism for the absorption and metabolic utilization of carbohydrates. Due to these imbalances in blood sugar metabolism, there is known to be more day-to-day (or within subject) variation in diabetic versus normal subjects in glycemic index testing, which influences the precision and may affect the mean of the GI results obtained (T.M.S. Wolever, The Glycaemic Index: A Physiological Classification of Dietary Carbohydrate. 2006.). Additionally, the testing procedure for diabetic individuals is distinctly different and more complex from that of normal individuals because of the impaired homeostatic mechanism in diabetic individuals. Without considering these important and crucial elements when conducting GI testing (or lack thereof), errors can be introduced and may not produce meaningful and useful results. In summary, there is simply no suggestion coming from any of the cited references as to how low the glycemic index should be or how high the carbohydrate content should be, and no prediction of any success in arriving at Applicants' claimed food item, both of which are needed to make a proper obviousness rejection. Reconsideration and withdrawal of this rejection are thus respectfully requested.

Applicants submit that it is improper to reject any of these claims under 35 U.S.C. 103(a). A *prime facie* case of obviousness has not been established. In summary, claims 1-18 are not anticipated or rendered obvious in view of the cited prior art since the references do not teach or suggest the features of the invention as claimed. Withdrawal of all claim rejections under 35 U.S.C. §103 is thus respectfully requested.

CONCLUSION

In view of the foregoing remarks and amendments, it is respectfully submitted that this application is in condition for allowance and allowance thereof is respectfully requested.

Respectfully submitted,

Saul Katz, *et al.*

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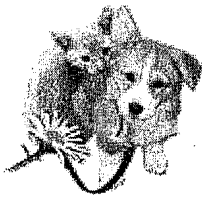
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Nutritional Difference

of Dogs & Humans



The Nutritional Differences Between Dogs and Humans
By: Jane R. Bicks, D.V.M.



Most of us consider our dogs to be members of the family, which makes it easy to forget they have different dietary needs than we do.

Few can resist a dog begging for table scraps, especially if it is a puppy. But no matter how human your dog behaves, whether it wakes you up with a wet kiss, expresses opinions about your friends, or cons you into giving up your side of the bed, it's digestive system and metabolism are uniquely canine.

Some specific differences between dogs and humans include:

* Amino acid requirements, and thus protein requirements, are different for dogs than for humans. Human adults require 8 essential amino acids, and babies need 9, while adult dogs require 9 amino acids, and puppies need 10.

* While vitamin C is considered an essential vitamin in humans because we can't make it and must have it, it's not considered essential for dogs. They form vitamin C in their liver.

* Humans need to monitor their cholesterol levels, which generally rise in proportion to the amount of fat or meat in the diet. However, although a dog's cholesterol levels can become abnormally elevated, a meal high in saturated fats is just what they need.

* Dogs must have meat in their diet to be in optimum health. A dog's sharp canine teeth are evidence of their need to tear apart raw meat, and thus their requirement for meat. Humans, on the other hand can eat a vegetarian diet with high grain, and maintain optimum health.

* Dogs can't handle as much cereal as humans. One reason is that humans and dogs differ in the amount of enzymes they

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make that are needed to break down carbohydrates. Dogs have about 80% less enzymes to break down carbohydrates than people do.

* Dogs can't handle large amounts of fiber, while humans can. When dogs are fed large quantities of fiber, it can result in constipation, excessive stool output, decreased nutrient digestion, and poor visual appearance.

* Since a dog's sense of smell is so much more sensitive than a person's a dog is less likely to eat spoiled or rancid food than we are.

* A puppy has a greater need to drink the mother's first milk (colostrum) than does a newborn child. Colostrum delivers immunity to newborns, as does the placenta. A child gets a great deal of immunity from the placenta, while a puppy gets less; thus the more important colostrum is to a puppy.

* A dog's milk contains different nutrients than a human's milk; thus a puppy can't be fed a baby formula.

* A newborn puppy requires more iron and copper than a human infant does.

* A human athlete will "carbohydrate load" before an event, while a dog athlete (sled dog) will be given high quantities of fat just before and during the event.

* A baby can begin solid food at four months, while a puppy can begin as early as six weeks.

* The gestation period for humans is nine months, while a dog's is two months. That means that a human's nutritional pregnancy demands last way longer than a dog's.

* While chocolate can have negative effects on dogs and humans, they are different. Excessive chocolate eating can make a human fat and, because of the caffeine, nervous. Chocolate, even in small amounts, can kill a dog.

Most nutritionists agree that a human diet should not contain more than 15% protein. While the protein requirement in dog food depends on the amount of fat, amino acids, and other nutrients in the food, a minimum of 18% protein is a safe requirement for an adult food. However, as with humans, a dog's nutrition is based upon adequate intake of three main ingredients: protein, carbohydrates, and fat.

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ORIGINAL COMMUNICATION

Determination of the glycaemic index of foods: interlaboratory study

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Objective: Practical use of the glycaemic index (GI), as recommended by the FAO/WHO, requires an evaluation of the recommended method. Our purpose was to determine the magnitude and sources of variation of the GI values obtained by experienced investigators in different international centres.
Design: GI values of four centrally provided foods (instant potato, rice, spaghetti and barley) and locally obtained white bread were determined in 8–12 subjects in each of seven centres using the method recommended by FAO/WHO. Data analysis was performed centrally.
Setting: University departments of nutrition.
Subjects: Healthy subjects (28 male, 40 female) were studied.
Results: The GI values of the five foods did not vary significantly in different centres nor was there a significant centre × food interaction. Within-subject variation from two centres using venous blood was twice that from five centres using capillary blood. The s.d. of centre mean GI values was reduced from 10.6 (range 6.8–12.8) to 9.0 (range 4.8–12.6) by excluding venous blood data. GI values were not significantly related to differences in method of glucose measurement or subject characteristics (age, sex, BMI, ethnicity or absolute glycaemic response). GI values for locally obtained bread were no more variable than those for centrally provided foods.
Conclusions: The GI values of foods are more precisely determined using capillary than venous blood sampling, with mean between-laboratory s.d. of approximately 9.0. Finding ways to reduce within-subject variation of glycaemic responses may be the most effective strategy to improve the precision of measurement of GI values.
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Introduction

The glycaemic index (GI) is a classification of the blood glucose raising potential of carbohydrate foods. It is defined as the incremental area under the blood glucose response curve elicited by a 50 g available carbohydrate portion of a food expressed as a percentage of that after 50 g carbohydrate from a reference food taken by the same subject (Wolever *et al*, 1991). Many factors such as food form, particle size, cooking, processing and starch structure affect the GI (Björck *et al*, 1994). There is evidence that low GI foods improve blood glucose control in people with diabetes (Brand *et al*, 1991; Wolever *et al*, 1992a; Frost *et al*, 1994; Järvi *et al*, 1999; Gilbertson *et al*, 2001), reduce serum lipids

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in people with hypertriglyceridaemia (Jenkins *et al*, 1987a), prolong endurance during physical activity (Thomas *et al*, 1991), improve insulin sensitivity (Frost *et al*, 1998) and increase colonic fermentation (Jenkins *et al*, 1987b; Wolever *et al*, 1992b). In addition, low GI foods are associated with high HDL cholesterol (Frost *et al*, 1999) and reduced risk for developing diabetes (Salmerón *et al*, 1997a,b) and cardiovascular disease (Liu *et al*, 2000). These effects prompted a recent FAO/WHO consultation to endorse the usefulness of the GI in diet planning (FAO/WHO, 1998).

However, application of the GI is made difficult because the GI value of many common foods is not known. In addition, the GI values reported by different laboratories vary widely for some foods such as potato (Wolever *et al*, 1994; Soh & Brand-Miller, 1999) and rice (Foster-Powell & Brand-Miller, 1995). Differences in GI values of similar foods reported by different investigators could be due to real differences in starch structure or digestibility, variation in methodology, or to the effects of random variation (Wolever *et al*, 1991). It is difficult to know how much each of these effects contributes to the variation of GI values because the performance of GI methodology has not been assessed. Therefore, the main objective of this study was to determine the magnitude of variation of the GI values of the same foods determined by experienced investigators using their usual procedures in different laboratories around the world. The usual methods for taking blood samples and measuring blood glucose and the demographic characteristics and ethnic background of subjects vary in the different participating laboratories. Although these variables are not thought to have a major effect (FAO/WHO, 1998), we were interested to know whether they were associated with any difference in the GI results obtained.

Methods

Coordination of interlaboratory testing

Seven research groups, experienced in GI methodology, participated in this study: Toronto, Canada; Lund, Sweden; Sydney, Australia; Milan, Italy; Dunedin, New Zealand; Trinidad, West Indies; and Potchefstroom, South Africa. The Toronto-based centre was the central laboratory which coordinated the delivery of the test foods, protocol and data analysis. The seven research groups were each sent four identical test foods and the reference food (described below) from the central laboratory. Each laboratory used its usual protocol, which was in line with the procedures recommended by the FAO/WHO (1998). However, these recommendations allow variation in blood sampling (capillary or venous), glucose analysis method and whether glucose is measured in whole blood or plasma.

Test foods

The four centrally provided foods were: instant mashed potato (Idahoan Foods, Lewisville, ID, USA), long grain rice (Star Brand, Goudas Food Products, Concord, Ontario, Canada), white spaghetti (Unico, Concord, Ontario, Canada) and pot barley (Goudas Food Products, Concord, Ontario, Canada). These foods, selected to provide a wide range of GI values, were purchased in Toronto and sent by courier to the participating laboratories with instructions about portion sizes to use and cooking instructions, which were generally according to package directions (except instant potatoes were prepared with water instead of milk). In addition, each of the research groups determined the GI value of a regular white bread produced in their area. Anhydrous glucose (Sigma Chemical Co., St Louis, MO, USA), dissolved in water was used as the reference food at each research centre. Each of the five test foods and the reference food were fed as portions providing 50 g of available carbohydrate, defined as total carbohydrate by difference minus dietary fibre. Some centres randomized the order of all eight trials, whereas others gave glucose as the first and last trials and randomized the order of the other six trials. Most subjects conducted one trial of each test food and three trials of the reference food. However, one centre studied two different portion sizes of barley (see below), and only repeated the reference food trial twice instead of three times. At another centre, subjects repeated both the glucose and the white bread trials three times (for a total of 10 trials done by each subject).

Portion sizes of instant potato (67.3 g), rice (64.9 g), spaghetti (72.3 g) and barley (79.6 g) were based on proximate and dietary fibre analysis using AOAC methods (AOAC, 1995). In one centre, the total and resistant starch contents of barley were measured using an *in vitro* technique (Åkerberg *et al*, 1998) and an additional trial done using a portion size calculated based on defining carbohydrate as total starch minus resistant starch. This resulted in a portion size of 93.9 g to compensate for the fact that 15.2% of the total starch was resistant starch. The portion size of white bread was based on local food tables.

Subjects

At each research centre, 8–12 normal, healthy subjects without diabetes were recruited to voluntarily participate in the study. Ethical approval for the study was obtained at each participating centre and all subjects gave informed consent to participate.

Experimental procedures

Subjects were studied on eight separate occasions in the morning after a 10–12 h overnight fast. After a fasting blood sample, subjects ate a test meal at a comfortable pace within 15 min and had further blood samples at 15, 30, 45, 60, 90 and 120 min after starting to eat. Test meals were served with a drink of the subject's choice (water, coffee or tea with milk if desired, but no sugar). The drink chosen by each subject remained constant for each of the eight trials.

Blood could be obtained by finger-prick or venepuncture and whole blood or plasma glucose measured by any recognized method. The method of blood sampling and glucose measurement remained standard for the duration of the study at each centre. Two centres measured whole capillary blood glucose using an automatic analyser (YSI Stat2300, Yellow Springs, OH, USA). One centre measured whole capillary blood glucose by glucose oxidase after mixing 1 ml 0.025 M NaOH and 50 µl 0.3 M $ZnSO_4$ solution with 50 µl whole capillary blood. Four centres measured plasma glucose by a hexokinase method, two obtaining plasma from capillary and two from venous blood samples.

Data analysis

Data were sent to the coordinating centre (Toronto) for statistical analysis. The incremental area under the blood glucose response curve (AUC), ignoring area beneath the baseline, was calculated geometrically (FAO/WHO, 1998).

The mean, s.d. and coefficient of variation (CV = 100 × s.d./mean) of the AUC of each subject's repeated glucose trials (reference food) were calculated. The AUC for each food taken by each subject was expressed as a percentage of the mean AUC for the reference food (glucose) taken by the same subject; the mean of the resulting values was the food GI. To determine the effect of using only a single trial of the reference food in calculating the GI, one glucose trial was selected at random for each subject and the GI values calculated using the AUC for the randomly selected glucose trial. We also explored the effect of calculating the ratio the means, ie $100 \times F/R$, where F = the mean of all subjects' AUC for the test food, and R = the mean of all subjects' AUC for the reference food, to see whether this would reduce between centre variation.

Theoretical considerations suggest that the distribution of GI values is skewed if large variability of glycaemic response areas exists (Wolever *et al*, 1991). Since some of the differences in methods used in the different centres appeared to affect the variability of the glycaemic responses, the distribution of GI values calculated in different ways was determined. To remove the variation in GI due to differences between foods, GI values were adjusted for the difference between the median value for each food and instant potato (instant potato was chosen because otherwise the adjustment would have resulted in some negative values). For example, the median GI value for instant potato was 85.7 and that for bread was 70.5; thus, the bread GI values were adjusted by adding 15.2. D'Agostino's test (test statistic is termed '*D*') was used to determine whether the values were normally distributed (Zar, 1984).

The data were subjected to analysis of variance (ANOVA) with repeated measures to examine for differences between subjects, centres and foods and the interaction between centre and foods. After demonstration of significant heterogeneity, the significance of differences between individual means was determined with Tukey's test to control for multiple comparisons. The test was modified to compare groups of unequal sizes by using a pooled value for n, eg for the 35 groups (five foods, seven centres) pooled $n = 35/(1/n_1 + 1/n_2 + \cdots + 1/n_{35}) = 9.58$. Single and multiple linear regression analyses were performed using Lotus 123 (Lotus Development Corp, Cambridge, MA, USA). For categorical variables (capillary or venous blood, plasma or whole blood glucose, male or female, Caucasian or non-Caucasian), dummy variables (0 or 1) were used in the regression analyses. Differences were considered significant if $P < 0.05$ (two-tailed).

Results

A total of 68 subjects was studied, 28 male and 40 female, median age 25 y (range 19–50) with median body mass index (BMI) 23.0 kg/m^2 (range 16.8–35.0). The gender distribution of subjects did not differ significantly between centres ($\chi^2 = 9.6$ d.f. = 6, $P = 0.14$), however, differences in age and BMI were significant (Table 1). There were 52 Caucasian subjects (including European and Scandinavian), eight East Indian, two African, two Middle-Eastern, one Chinese, one North American Indian and two mixed. Centres differed significantly with respect to the ethnicity of

Table 1 Characteristics of subjects participating at each centre

Centre	*Method*[a]	n (M:F)	*Age (y)*	*BMI (kg/m^2)*	*Reference AUC*[b] *(mmol × min/l)*	*Reference CV*[c] *(%)*
A	CBY	4:4	30.1 ± 3.4^{B}	20.8 ± 0.6^{B}	153 ± 17^{BC}	28.8 ± 4.9^{B}
B	CBY	5:5	36.3 ± 2.6^{A}	27.8 ± 1.3^{A}	210 ± 16^{B}	23.1 ± 4.3^{B}
C	CPH	5:4	24.9 ± 1.8^{BC}	20.9 ± 0.9^{B}	281 ± 27^{A}	25.6 ± 6.0^{B}
D	CPH	3:7	25.2 ± 2.4^{BC}	22.6 ± 0.3^{B}	174 ± 18^{BC}	19.3 ± 1.8^{B}
E	CBG	6:4	27.7 ± 1.0^{BC}	23.8 ± 0.5^{B}	162 ± 17^{BC}	21.5 ± 6.2^{B}
F	VPH	5:7	24.3 ± 0.9^{BC}	23.8 ± 0.4^{B}	158 ± 21^{BC}	53.4 ± 6.1^{A}
G	VPH	0:9	21.0 ± 0.5^{C}	21.6 ± 0.6^{B}	97 ± 16^{C}	61.3 ± 6.5^{A}
All		28:40	27.0 ± 0.9	23.2 ± 0.4	176 ± 9	33.7 ± 2.7

Values are means ± s.e.m.
[ABC]Means not sharing the same letter superscript differ significantly, $P < 0.05$.
[a]Method: C = capillary, V = venous, P = plasma, B = whole blood, Y = YSI, H = hexokinase, G = glucose oxidase.
[b]Reference AUC = mean incremental area under blood glucose response curve after the reference food (50 g glucose).
[c]Reference CV = mean coefficient of variation (100 × s.d./mean) of AUC for repeated reference food tests.

Table 2 Incremental areas under the curve for the test foods determined by the different research centres. All of the test foods, except white bread, were identical between centres

Centre	Potato	Bread	Rice	Spaghetti	Barley	Mean
A	126±45	112±29	83±39	58±24	51±17	86^{BCD}
B	188±59	133±39	123±46	88±40	62±37	119^{B}
C	252±101	185±89	237±102	189±45	133±61	199^{A}
D	171±63	120±37	109±36	74±20	42±19	103^{BC}
E	142±53	124±50	123±41	65±17	61±20	103^{BC}
F	95±72	97±51	90±48	47±30	34±36	72^{CD}
G	67±37	75±61	77±63	46±31	40±34	61^{D}
All[a]	$147±84^{X}$	$120±60^{X}$	$120±73^{X}$	$80±54^{Y}$	$59±45^{Y}$	

Values are means±s.d.
^{XY}Means with different letter superscripts differ significantly ($P<0.05$).
^{ABCD}Means with different letter superscripts differ significantly ($P<0.05$).
[a]Means for all subjects ($n=68$). ANOVA effects: food, $F_{4,24}=50.7$ ($P<0.001$); centre, $F_{6,24}=32.5$ ($P<0.001$); centre × food interaction, $F_{24,237}=1.77$ ($P=0.017$).

their subjects with Milan and Potchefstroom having all Caucasian subjects, Trinidad having no Caucasians and the other centres having from one to three subjects of non-Caucasian descent.

There were significant differences between centres for the mean AUC after the reference food (50 g glucose) and the CV of the repeated reference food AUC (CVref; Table 1). There was significantly greater within-subject variation of blood glucose responses in each of the two centres measuring glucose in venous plasma than each of those using capillary blood (Table 1). In the 47 capillary blood subjects, mean CVref, 23.4±2.1%, was significantly less than in the 21 venous blood subjects 56.8±4.4% ($P<0.001$). By linear regression analysis, type of blood sampling (capillary or venous) explained 47% of the variation in CVref ($P<0.001$). Adding the other six variables (age, sex, ethnicity, BMI, plasma or whole blood glucose, and mean AUC after reference food) to the model only accounted for an additional 3% of the variation of CVref (N.S.).

The mean CV of the AUC of repeated bread trials taken by 10 subjects, 27.7±5.0, did not differ significantly from that for their repeated glucose trials, 23.1±4.3.

The median-adjusted GI values for all five foods in all 68 subjects ($n=340$) were not normally distributed (mean±s.d., 88.8±32.3; median, 85.7; $D=0.2585$, N.S.). Since use of venous blood sampling was the only variable significantly associated with within-subject variability, the GI data from venous blood samples were excluded. The distribution of the remaining 235 values did not deviate significantly from a normal distribution (mean±s.d., 91.1±20.5; median, 90.1; $D=0.2780$, $P<0.05$). When only one trial of the reference food was used to calculate the GI, the resulting mean, s.d. and

Table 3 GI values for the test foods as determined by the different research centres. All of the test foods, except white bread, were identical between centres

Centre	Potato	Bread	Rice	Spaghetti	Barley	Mean
A	86.1±29.7	78.7±28.4	$54.8±24.1^{X}$	$38.7±13.2^{X}$	36.0±15.4	58.9
B	93.3±32.5	64.2±15.4	$62.6±25.0^{XY}$	$44.1±19.8^{XY}$	31.4±18.7	59.1
C	89.9±23.9	64.6±21.6	$85.0±28.6^{Y}$	$69.9±18.8^{Y}$	46.2±15.4	71.1
D	98.5±20.6	69.4±3.6	$63.3±8.1^{XY}$	$43.8±9.2^{XY}$	24.5±7.3	59.9
E	88.3±21.3	78.9±26.1	$76.9±12.9^{XY}$	$42.1±10.8^{XY}$	39.3±13.1	65.1
F	65.2±44.6	75.8±64.3	68.4±48.0	36.4±35.8	23.2±24.6	53.8
G	74.2±40.3	75.9±50.7	87.0±75.9	57.0±45.3	47.1±49.7	68.2
All[a]	$84.5±32.7^{A}$	$72.5±35.8^{A}$	$71.1±38.2^{A}$	$46.9±26.7^{B}$	$34.7±24.7^{B}$	
Venous[b]	$69.0±42.0^{AB}$	$75.8±57.5^{A}$	$76.4±60.5^{A}$	$45.2±40.4^{BC}$	$33.4±38.4^{BC}$	
Capillary[c]	$91.5±25.1^{A}$	$71.0±20.7^{B}$	$68.7±22.6^{B}$	$47.6±18.1^{C}$	$35.2±15.6^{C}$	

Values are means±s.d.
^{XY}Values in the same column with different letter superscripts differ significantly ($P<0.05$).
^{ABC}Values in the same row with different letter superscripts differ significantly ($P<0.05$).
[a]Means for all subjects ($n=68$). ANOVA effects: food, $F_{4,24}=38.8$ ($P<0.01$); centre, $F_{6,24}=2.09$ ($P<0.093$); centre × food interaction, $F_{24,237}=1.21$ ($P<0.24$).
[b]Means for subjects from capillary blood centres (A–E; $n=47$). ANOVA effects: food, $F_{4,16}=72.1$ ($P<0.001$); centre, $F_{4,16}=1.82$ ($P<0.17$); centre × food interaction, $F_{16,163}=2.25$ ($P=0.006$).
[c]Means for subjects from venous blood centres (F and G; $n=21$). ANOVA effects: food, $F_{4,4}=4.80$ ($P<0.002$); centre, $F_{1,4}=11.06$ ($P<0.029$); centre × food interaction, $F_{4,74}=0.29$ ($P=0.88$).

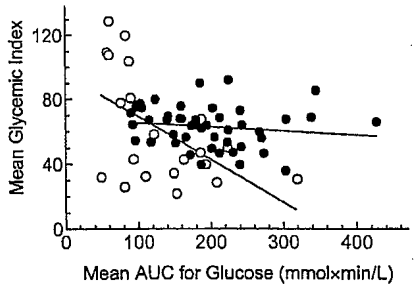


Figure 1 Relationship between mean incremental area under the curve for glucose and the mean GI value for 47 subjects from centres using capillary blood (•; $r=-0.14$, N.S.) and for 21 subjects from centres using venous blood (o; $r=-0.53$, $P=0.01$). The lines plotted are regression lines.

median values were higher than when GI was calculated using the mean of three reference trials. In addition, the distribution of the resulting GI values was not normally distributed either for all the GI values (mean±s.d., 101.7± 72.4; median, 88.8; $D=0.1885$, N.S.) or for the centres using capillary blood (mean±s.d., 96.4±24.3; median 93.8; $D=0.2755$, N.S.).

The mean incremental areas under the glycaemic respsone curves (AUC) for each food by centre are shown in Table 2. By ANOVA, AUC was significantly affected by subject, centre, food and food × centre interaction. The mean GI values for each food, by centre, are shown in Table 3. In one centre the portion size of barley was increased from 79.6 to 93.9 g to adjust for its resistant starch content. This resulted in a non-significant increase in GI from 39.3±13.1 to 44.4±13.1 (mean±s.d. $n=10$). By ANOVA GI was significantly affected by food, but there was no significant difference between centres and no centre × food interaction. There was a significant difference in GI between subjects ($F_{67,237}=2.04$, $P<0.001$), but subject GI was not significantly related to age, sex, BMI, ethnicity or type of blood sampling. GI was not significantly related to AUC for glucose in centres using capillary blood sampling ($r=-0.14$, N.S.), but with venous blood sampling GI was inversely related to AUC for glucose ($r=-0.53$, $P=0.013$; Figure 1).

Mean GI was not affected by type of blood sampling, but for centres using capillary blood sampling the s.d. were smaller in all cases than centres using venous blood (Table 3). The s.d. of the food GI values were positively related to their means in centres using venous blood ($P=0.005$) and centres using capillary blood ($P=0.002$, Figure 2a). The CV of the food GI values were negatively related to their means in centres using venous blood ($P=0.026$), but the relationship did not reach significance for centres using capillary blood ($P=0.080$, Figure 2b).

Considering only venous blood data, there were significant differences between foods and centres. Due to high random variation, there was no significant centre × food interaction, and the only difference in GI between foods

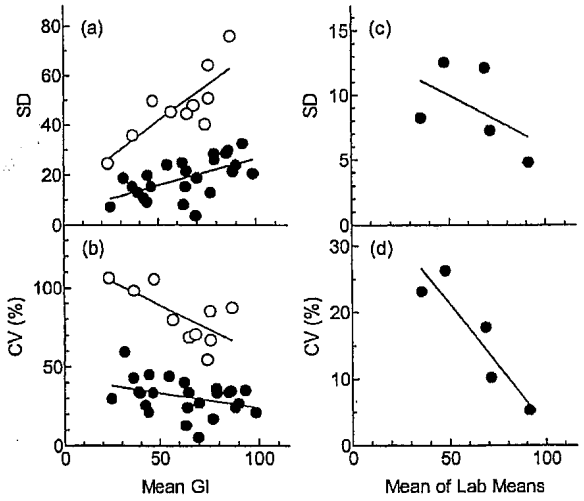


Figure 2 Relationships between mean GI and variation of GI for the five centres using capillary blood (•) and the two using venous blood (o); (a) mean and SD of GI values for five foods from capillary blood centres ($r=0.597$, $P=0.002$) and venous blood centres ($r=0.803$, $P=0.005$); (b) mean and CV of GI values for five foods from capillary blood centres ($r=-0.357$, $P=0.080$) and venous blood centres ($r=-0.695$, $P=0.026$); (c) mean and s.d. of laboratory mean GI values for five foods ($r=-0.518$, $P=0.37$); (d) mean and CV of laboratory mean GI values for five foods ($r=-0.912$, $P=0.031$).

was the difference between barley and bread (Table 3). For the capillary blood data, there was no significant difference between centres but there was a highly significant difference between foods (Table 3). The GI of all the foods differed significantly from each other, except for the difference between bread and rice, and the difference between barley and spaghetti. Because of low random variation, there was a significant centre × food interaction with higher GI values for spaghetti and rice in centre C than in centre A. None of the other differences in GI values for the same food tested in

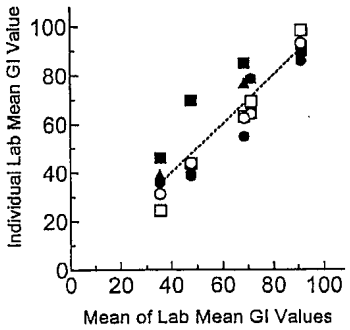


Figure 3 Individual centre mean GI values plotted against the mean of the centre mean GI values for the five foods (centres: A=•; B=o; C=■; D=□; E=▲). The dotted line is the line of identity.

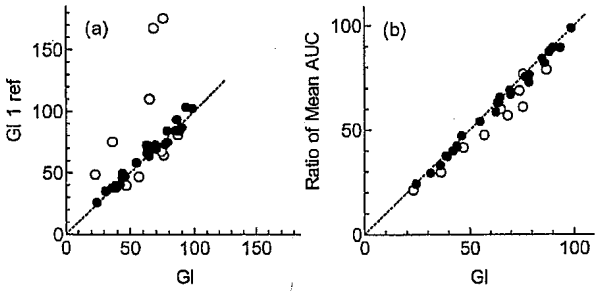


Figure 4 Plots showing individual laboratory mean GI values for the five foods for five centres using capillary blood (•) and two centres using venous blood (o); (a) GI *vs* GI calculated using one AUC value for the reference food (GI 1 ref); (b) GI *vs* mean AUC for test food expressed as a percentage of the mean AUC for the reference food (ratio of mean AUC). Dotted lines are lines of identity.

different centres were significant. There was significant heterogenity between subject's mean GI values ($F_{46,163} = 2.55$, $P < 0.001$) among the 47 subjects from whom capillary blood samples were obtained, with the values being normally distributed and ranging from 35.9 to 91.9. Individual subjects' GI values were not significantly related to age, sex, BMI or ethnicity.

The key question we wished to address was what is the variation in GI determination between centres. Since the use of venous blood sampling appeared to be associated with markedly different within-subject variation, we included in this analysis only the results for the five centres using capillary blood. The mean GI values for the five foods from these five centres are plotted against the mean in Figure 3. The s.d. of the centre mean GI values for the five foods (potato, bread, rice, spaghetti and barley, respectively) are 4.8, 7.8, 12.2, 12.6 and 8.2. These s.d.s were not related to their means (Figure 2c), although their CVs were significantly related to their means (Figure 2d). From these data, therefore, we estimate the average s.d. for GI values estimated in 8–12 subjects by different laboratories is 9.0 resulting in a 95% confidence interval of about 18.

Figure 4a shows the relationship between the centre mean GI values for each food calculated using the mean of three reference trials (GI) *vs* using one reference trial (GI_1). For capillary blood centres, mean GI_1, 64.9, was 2.1 greater than mean GI, 62.8, with the difference in venous blood centres being 26.7 (87.7 *vs* 61.0). The mean s.d. for GI_1 values in the five capillary blood centres, 9.1, was slightly greater than the mean s.d. for the GI values, 9.0. Figure 4b shows the relationship between the centre mean GI values for each food *vs* the ratio of the mean AUC values (*F*/*R*). For capillary blood centres, mean *F*/*R* (61.3) was 1.5 less than mean GI (62.8), with the difference in venous blood centres being −6.7 (54.4 *vs* 61.0). The mean s.d. for *F*/*R* values in the five capillary blood centres, 8.9, was slightly less than the mean s.d. for the GI values, 9.0.

Discussion

The main purpose of this study was to estimate the magnitude of variation in GI determination between experienced laboratories. Neither type of blood sampling, method of glucose analysis, use of repeated reference food trials, age, sex, ethnicity and BMI of the subjects, type of reference food, nor inclusion of resistant starch within a food's available carbohydrate content appeared to have an appreciable effect on the *mean* GI value obtained. However, several of the variables were associated with a major effect on the *distribution* and *variability* of GI values and hence on the confidence limits of the means.

The major finding of this study was that the average s.d. of laboratory mean GI values for the five foods was 9.0. The magnitude of between centre variation was not reduced by expressing the mean AUC for each food as a percentage of the mean AUC for the reference food (glucose). The s.d. of 9 applies for mean GI values determined in 8–12 subjects. The interlaboratory s.d. was relatively constant across the wide range of mean GI values represented (35–91). The implication of this finding is that when published GI values of the 'same' food determined by different laboratories (particularly those represented here) differ by more than 18, then it is likely that the difference represents a true difference in GI rather than a chance finding. For example, Soh and Brand-Miller (1999) reported GI values for three varieties of mature boiled potatoes of 89, 103, 89 and one variety of mashed potatoes of 93. By contrast, Wolever *et al* (1994) reported GI values of two varieties of mature potatoes to be 59 and 64 when boiled, and 74 when mashed. Since all the values from one lab differ from those of the other by >18, it is likely that the GI values of Australian potatoes really differ from those Canadian potatoes.

Current recommendations are that capillary blood sampling is preferred for determining the GI, but that it is acceptable to use venous blood sampling (FAO/WHO, 1998). We found that the use of venous plasma was associated with greater within-subject variation of both glycaemic responses and GI values, and non-normal distribution of GI values. The latter is probably related to the former because the GI is the ratio of two independently variable numbers. Increased variation of the numbers will have the effect of skewing the distribution of the resulting ratios (Wolever *et al*, 1991). Thus, the present data are consistent with previous results showing that glycaemic responses measured in venous plasma are lower and more variable than those in simultaneously obtained capillary blood (Wolever & Bolognesi, 1996).

The concentration of glucose in venous blood is lower than that in capillary blood because, as blood flows from the arterial to the venous circulation via the capillaries, peripheral tissues remove some of the glucose. The rise in blood insulin and glucose after eating stimulates glucose removal by tissues; thus, the difference in glucose concentration between artillery and venous blood is greater postprandially than fasting, leading to a smaller glucose rise in venous blood (Jackson *et al*, 1973; Coppack *et al*, 1990).

Venous glucose responses may be more variable than capillary responses for several reasons. Blood glucose concentrations oscillate on a minute-by-minute basis (Abdallah *et al*, 1997), driven, at least in part, by the pulsatile nature of insulin secretion (Matthews *et al*, 1983). Presumably, the oscillations of plasma glucose in different tissues in the body are not in phase with each other, because it takes different lengths of time for the pulses of insulin from the pancreas to reach them. Thus, it is possible that the magnitude of glucose oscillations in forearm venous blood may be greater than those in capillary blood because the vein drains a small volume of tissue with insulin oscillations in phase with each other. However, the glucose oscillations in capillary blood may be damped because arterial blood is derived from all tissues in the body with insulin concentrations oscillating out of phase with each other. Furthermore, there is a small analytical error associated with measuring glucose, and this has a larger proportional effect on the AUC when the rise in glucose is small. For example, a 0.1 mmol/l difference in the fasting glucose concentration results in a 12 mmol min/l difference in the AUC over 2 h, which is 20% of an AUC of 60, but only 6% of an AUC of 200.

The greater validity of using capillary rather than venous blood sampling is also suggested by the lack of relationship, for capillary blood, between the mean GI of individual subjects and the mean AUC for the reference food (Figure 2), but the existence of a significant correlation with venous blood. Correlation between a ratio and its denominator is a common problem of using ratios (Allison *et al*, 1995) and indicates that the ratio does not control adequately for the denominator. This is important because the GI is intended to control for the glycaemic responses of different subjects.

Subject characteristics such as age, sex, BMI and ethnicity may have contributed to the highly significant differences in absolute glycaemic responses between subjects. However, these factors had no significant effect on the GI values obtained in this study. This is consistent with previous data in subjects with diabetes (Wolever *et al*, 1990), which suggests that most of the variation of GI values is due to within-subject variation (Wolever, 1992).

The mean AUC of three trials of the reference food should be used to calculate the GI (FAO/WHO, 1998) because the mean of three trials is more likely to be representative of a subject's true glycaemic response to the reference food than the result of a single trial. Since the reference food response is used to calculate the GI value for every food, an unrepresentative value for the reference AUC affects the GI value of every food tested and may make that subject's mean GI value differ from that of other subjects. A mathematical model showed that, using the mean of 3, compared with one standard trial, to calculate GI values resulted in more normally distributed GI values with reduced variability and a lower mean (Wolever *et al*, 1991). Our results are consistent with this in that the use of one randomly selected AUC value for the reference food to calculate the GI resulted in non-normally distributed GI values with a higher mean and s.d.

Wolever *et al* (1991) have advocated the use of white bread as the reference food instead of glucose because it represents a more physiological meal. However, variation in the composition and digestibility characteristics of white bread with location and time would reduce its usefulness as the reference food. In this study, bread was the only locally obtained food and the portion size was based on local food tables. Despite this, the variability of the GI values for bread was similar to those for the other foods. This suggests that variation in the composition of white bread, at least from the cities represented here, is not large enough to alter its GI value, and thus supports the validity of using bread as the reference food. Nevertheless, glucose is a more logical and easily standardized reference food for international use. GI values based on glucose have been used in Australia for several years (Brand-Miller *et al*, 1996). Thus, for international standardization, we recommend that GI values of foods be expressed relative to glucose. GI values obtained using bread as the reference food can be adjusted to the glucose standard by dividing them by 1.4.

There are different ways of defining and measuring carbohydrate, dietary fibre and resistant starch (RS; FAO/WHO, 1998) in different countries. Thus, the portion size of food containing 50 g carbohydrate may vary in different laboratories depending on the definitions used. Since glycaemic responses are related to the amount of carbohydrate ingested (Wolever & Bolognesi, 1996), use of a smaller portion size will result in a lower GI value. The GI is an index of the blood glucose raising potential of the available or glycaemic carbohydrate in foods. Carbohydrates which do not provide glucose for metabolism, such as non-starch polysaccarides and RS (Englyst *et al*, 1992), should not be included in the portion of carbohydrate tested. However, standardized methods for measuring RS are not available (FAO/WHO, 1998). Since the impact of excluding RS on the GI is not known, we chose barley, a food with a high RS content, to test this. After excluding RS, the smaller portion size contained 44.2 g of glycaemic starch. Increasing carbohydrate intake from 44.2 to 50 g would be expected to increase the glycaemic response by about 8% (Wolever & Bolognesi, 1996). Although the 13% higher GI value found for the higher portion size of barley was similar to the expected difference, the difference was not significant. Over 300 subjects would be needed for an 80% chance of detecting a difference of 8% at $P < 0.05$.

We conclude that the mean of at least three repeated trials of the standard food should be used to calculate the GI. The most precise and accurate determination of the GI may be achieved using capillary rather than venous blood sampling, but prospective studies are needed to confirm this. The estimated between-laboratory standard deviation of GI values is 9.0. Between-laboratory variation in GI appears to be related to random, day-to-day variation of glycaemic responses within subjects. Thus, finding ways to reduce within-subject variation in glycemic responses may be the most effective strategy to improve the precision of measurement of GI values.

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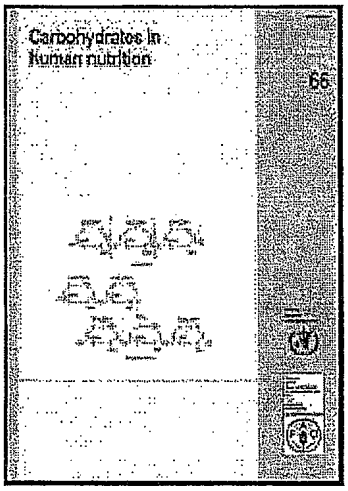


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Preface

Carbohydrates are the single most important source of food energy in the world. They comprise some 40 to 80 percent of total food energy intake, depending on locale, cultural considerations or economic status. Those persons with high carbohydrate diets are often in the lower economic strata as foods high in carbohydrate, such as cereal grains, are most often the least expensive. Rice is an excellent example and is the primary staple in the diet of much of the world's population.

Food carbohydrates are not only an energy source, however, they have other roles as well. Typically, sugars are used as sweeteners to make food more palatable and to assist in food preservation. Diets high in carbohydrate may reduce individual propensity to obesity, and there is some evidence that such diets may also provide some protection against various non-communicable human diseases and conditions.

The concept of dietary fibre has changed. Fibre was originally described as plant cell wall material which simply passed through the gut unchanged and provided bulk to feces. Today it is known as an important moderator of digestion in the small bowel and as a major substrate for fermentation in the colon, where the non-starch polysaccharides of the plant cell wall are metabolized to short chain fatty acids. Absorption of the latter provides some energy. In addition, it has been shown that other carbohydrates are present in the diet which enter the colon and are fermented, including resistant starch and non-digestible oligosaccharides.

A previous Joint Expert Consultation on Carbohydrates in Human Nutrition, held in 1979, was wide ranging in scope. The report of that consultation (1) is essentially a reference document outlining the knowledge at that time of the various roles that carbohydrates have in the human diet. Included were the effects of processing on carbohydrates as well as carbohydrate digestion, absorption and metabolism. Of special concern to the consultation were the diets of infants and children. That consultation reached several conclusions regarding each of the areas discussed, and made a number of recommendations for future work.

The Joint FAO/WHO Expert Consultation on Carbohydrates in Human Nutrition was held in Rome from 14 to 18 April 1997. The Consultation was opened by Dr. H. de Haen, Assistant Director-General, Economic and Social Department, FAO, who welcomed the participants on behalf of the Directors-General of FAO and WHO.

In welcoming the participants. Dr. de Haen recalled the previous joint consultation on this subject, which was held in Geneva in 1979. That and the present Consultation are part of a long series of such expert consultations which have as a primary objective the review of the state of knowledge on the role of various nutrients in the human diet and the formulation of practical recommendations where interpretation is needed or controversy exists. The most recent in this series was the Joint FAO/WHO Expert Consultation on Fats and Oils in Human Nutrition held in Rome in 1993.

Consultations such as this are part of a continuing commitment by both FAO and WHO to promote a reliable, nutritious and safe food supply and to provide scientifically sound nutritional advice to member nations. This commitment was recently reaffirmed at the World Food Summit held in November 1996 in Rome.

Dr. de Haen pointed out that the understanding of the role that carbohydrates play in human nutrition and health has made great strides in the 18 years since the previous carbohydrate consultation. Progress in carbohydrate chemistry has permitted the development of a variety of new food products, many of which are based on improved nutritional considerations. Perhaps the greatest impact of recent knowledge is our growing understanding of the diverse physiological roles that carbohydrates have, depending to a great extent on the site, rate and extent of their digestion and fermentation in the gut. This is leading to new dietary approaches, not only for better nutrition, but for improved health as well. Another understanding which has come about in recent years is the influence of carbohydrates on physical performance through glycogen loading. This technique is now well-established as an important factor for the improvement of endurance performance and capacity.

With these new advances in carbohydrate understanding come new issues which have important implications for agricultural production, the food industry and public health policy. Dr. de Haen pointed out that this Consultation will be addressing a number of these issues, and underlined the importance of the Consultation in providing international guidance in this broad area.

Dr. de Haen reminded the participants that they had been invited to the Consultation as independent experts and that their participation in the Consultation was to be in their individual capacity and not as a representative of any organization, affiliation or government.

Dr. Graeme Clugston, Director, WHO Nutrition Programmes, added his welcome to the participants, on behalf of the Director-General of WHO. Dr. Clugston pointed out that the formulation and implementation of science-based dietary guidelines have become a central issue for the nutritional sciences, as well as a major challenge for governments world wide, especially since the International Conference on Nutrition held in Rome, December 1992.

Research during the last two decades has firmly established that diet is one of the major risk factors in the development of a spectrum of non-communicable diseases. Dr. Clugston outlined some of the critical issues in this area, including the roles of mono- and disaccharide's and starch as distinct from non-starch polysaccharides, their relation with dietary fats, and their contribution to dietary energy intakes. Obesity, non-insulin dependent diabetes, coronary heart disease, some cancers (notably colocrectal) and other gastrointestinal tract conditions are among the diseases which can be beneficially influenced by dietary carbohydrates. However, frequent consumption of sugar and other fermentable carbohydrates throughout the day increases the cariogenic risk potential of the diet, especially in the absence of reasonable oral hygienic practices. On the other hand, sugar intake plays a less important role in caries causation if fluoridation and hygienic measures have been taken.

Dr. Clugston expressed confidence that this Expert Consultation would lead to scientifically sound, up-to-date, pragmatic recommendations on carbohydrates in human nutrition. FAO and WHO would then ensure that these recommendations

would be passed on to all member states world wide, providing them with the best possible guidance for developing their own appropriate dietary guidelines for health promotion, good nutrition and disease prevention.

The Consultation elected Dr. David Lineback as Chairman and Dr. Ruth Oniang'o as Vice-Chair. Dr. Mark Wahlquist and Dr. Thomas Wolever were appointed jointly as Rapporteurs. Dr. Lineback in his response indicated the importance of this Consultation and outlined the scope of the issues that would be discussed and on which the two agencies, FAO and WHO, were seeking expert guidance from the Consultation.



Chapter 1 - The role of carbohydrates in nutrition

Description
Availability and consumption
Physiology

Description

Carbohydrates are polyhydroxy aldehydes, ketones, alcohols, acids, their simple derivatives and their polymers having linkages of the acetal type. They may be classified according to their degree of polymerization and may be divided initially into three principal groups, namely sugars, oligosaccharides and polysaccharides (see Figure 1).

Figure 1

The major dietary carbohdrates

Class (DP*)	Sub-Group	Components
Sugars (1-2)	Monosaccharides	Glucose, galactose, fructose
	Disaccharides	Sucrose, lactose, trehalose
	Polyols	Sorbitol, mannitol
Oligosaccharides (3-9)	Malto-oligosaccharides	Maltodextrins
	Other oligosaccharides	Raffinose, stachyose, fructo-oligosaccharides
Polisaccharides (>9)	Starch	Amylose, amylopectin, modified starches
	Non-starch polisaccharides	Cellulose, hemicellulose, pectins, hydrocolloids

DP * = Degree of polymerization

Each of these three groups may be subdivided on the basis of the monosaccharide composition of the individual carbohydrates. Sugars comprise monosaccharides, disaccharides and polyols (sugar alcohols); oligosaccharides include malto-oligosaccharides, principally those occurring from the hydrolysis of starch, and other oligosaccharides, e.g. α -galactosides (raffinose, stachyose etc.) and fructo-oligosaccharides; the final group are the polysaccharides which may be divided into starch (α -glucans) and non-starch polysaccharides of which the major components are the polysaccharides of the plant cell wall such as cellulose, hemicellulose and pectin (2,3,4).

Total carbohydrate

Although the individual components of dietary carbohydrate are readily identifiable, there is some confusion as to what comprises total carbohydrate as reported in food tables. Two principal measures of total carbohydrate are used, firstly, that derived by "difference" and secondly the direct measurement of the individual components which are then combined to give a total. Calculating carbohydrates by "difference" has been used since the turn of the century. The protein, fat, ash and moisture content of a food are determined, subtracted from the total weight of the food and the remainder, or "difference", is considered to be carbohydrate. There are, however, a number of problems with this approach to total carbohydrate analysis in that the "by difference" figure includes a number of non-carbohydrate components such as lignin, organic acids, tannins, waxes, and some Maillard products. In addition to this error, it combines all of the analytical errors from the other analyses. Finally, a single global figure for carbohydrates in food is uninformative because it fails to identify the many types of carbohydrates in a food and thus to allow some understanding of the potential physiological properties of those carbohydrates (5,6).

Terminology

In deciding how to classify dietary carbohydrate the principal problem is to reconcile the various chemical divisions of carbohydrate with that which reflects physiology and health. A classification based purely on chemistry does not allow a ready translation into nutritional terms since each of the major classes of carbohydrate have a variety of physiological effects. However, a classification based on physiological properties also creates a number of problems in that it requires a single effect to be considered as overridingly important and to be used as the basis of the classification. This dichotomy has led to the introduction of a number of terms to describe various fractions and sub-fractions of carbohydrate (4,7).

Sugars

The term "sugars" is conventionally used to describe the mono and disaccharides. "Sugar", by contrast, is used to describe purified sucrose as are the terms "refined sugar" and "added sugar"

Extrinsic and intrinsic sugars

These terms had their origin in a United Kingdom (UK) Department of Health committee in 1989 (8), which was looking at the question of sugars in the diet. The terms were developed to help the consumer choose between what were considered to be healthy sugars and those which were not. Intrinsic sugars were defined as sugars occurring within the cell walls of plants, i.e. naturally occurring, while extrinsic sugars were those which were usually added to foods. Because lactose in milk is also an extrinsic sugar, an additional phrase "non-milk extrinsic sugars" was developed. These terms have not gained wide acceptance either in the UK or other countries in the world. There are no current plans to measure these sugars separately in the diet nor to incorporate their use into food tables.

Complex carbohydrates

This term was first used in the McGovern report, "Dietary Goals for the United

States" in 1977 (9). The term was coined largely to distinguish sugars from other carbohydrates and in the report denotes "fruit, vegetables and whole-grains". The term has since come to be used to describe either starch alone, or the combination of all polysaccharides. It was used to encourage consumption of what were considered to be healthy foods such as whole-grain cereals, etc., but becomes meaningless when used to describe fruit and vegetables which are low in starch. Furthermore, it is now realized that starch, which is by any definition a complex carbohydrate, is variable metabolically with some forms being rapidly absorbed and having a high glycemic index and some being resistant to digestion. The term "complex carbohydrate" has encompassed, at various times, starch, dietary fibre and non-digestible oligosaccharides. As a substitute term for starch, however, it would seem to have little merit and, in principle, it is better to discuss carbohydrate components by using their common chemical names.

Available and unavailable carbohydrate

A major step forward conceptually in our understanding of carbohydrates was made by McCance and Lawrence in 1929 (10) with the division of dietary carbohydrate into available and unavailable. In an attempt to prepare food tables for diabetic diets they realised that not all carbohydrates could be "utilized and metabolized", i.e. provide the body with "carbohydrates for metabolism". Available carbohydrate was defined as "starch and soluble sugars" and unavailable as "mainly hemicellulose and fibre (cellulose)". This concept proved useful, not the least because it drew attention to the fact that some carbohydrate is not digested and absorbed in the small intestine but rather reaches the large bowel where it is fermented. It suggests that the site of digestion or fermentation in the gut of carbohydrate is of overriding importance. However, it is misleading to talk of carbohydrate as "unavailable" because some indigestible carbohydrate is able to provide the body with energy through fermentation. There are many properties of carbohydrate of which digestibility and fermentability are only two. A more appropriate substitute for the terms "available" and "unavailable" today would be to describe carbohydrates as either as glycemic (i.e. providing carbohydrate for metabolism) or non-glycemic, which is closer to the original concept of McCance and Lawrence.

Resistant starch

One of the major developments in our understanding of the importance of carbohydrates for health in the past twenty years has been the discovery of resistant starch. Resistant starch is defined as "starch and starch degradation products not absorbed in the small intestine of healthy humans" (11). The main forms of resistant starch are physically enclosed starch, e.g. within intact cell structures (RS_1), some raw starch granules (RS_2) and retrograded amylose (RS_3) (11,12).

Modified starch

The proportions of amylose and amylopectin in a starchy food is variable and can be altered by plant breeding. Techniques using genetic engineering are rapidly emerging, enabling starches to be produced for specific purposes by genetically modifying the crop used for their production. High amylose corn starch and high amylopectin (waxy) corn starch have been available for a long time, and display quite different functional as well as nutritional properties. High amylose starches require higher temperatures for gelatinization and are more prone to retrograde

and to form amylose-lipid complexes. Such properties can be utilized in the formulation of foods with low glycemic index and/or high resistant starch content.

Physical modifications of starches include pregelatinization and partial hydrolysis (dextrinization). Chemical modification is mainly the introduction of side groups and cross-linking or oxidation. These modifications may be used to decrease viscosity and to improve gel stability, mouthfeel, appearance and texture, and resistance for heat treatment (13). The application of modified starches as fat replacers is another important area. Some modified starches may be partly resistant to digestion in the small intestine, thereby adding to resistant starch (14).

Dietary fibre

The original description of dietary fibre by Trowell in 1972 (15) was "that portion of food which is derived from cellular walls of plants which is digested very poorly by human beings". This is not an exact description of any carbohydrate in the diet but is more a physiological concept. It was linked by Burkitt and Trowell to the etiology of a number of "Western diseases" (16) and on the basis of this a hypothesis relating fibre to health was developed. The use of the term has, however, caused many difficulties over the years because of controversies regarding definition. Moreover, the proposal that there are a number of dietary fibre deficiency disorders is an over-simplification and needs to be modified now in the light of new knowledge of diet and disease.

The main components of dietary fibre are derived from the cell walls of plant material in the diet and comprise cellulose, hemicellulose and pectin (the non-starch polysaccharides). Lignin, a non-carbohydrate component of the cell wall is also often included. Dietary fibre is a term which is felt to be valuable for the consumer who looks upon this as a healthy component of the diet. At the present time there is no consensus as to which components of carbohydrate should be included as dietary fibre and different authors have variously included non-starch polysaccharides and resistant starch. More recently it has been suggested that non-digestible oligosaccharides should also be included. Dietary fibre has also been defined by method. While there is general agreement that the non-starch polysaccharides are the principal part of dietary fibre there is currently no consensus as to whether other components should be included in this term. It has been suggested that the use of the term dietary fibre be gradually phased out (1,17). Its widespread use and popularity with the consumer has made this difficult in practice and the term has been useful in nutrition education and product development.

Soluble and insoluble fibre

These terms developed out of the early chemistry of non-starch polysaccharides which showed that the fractional extraction of these polysaccharides could be controlled by changing the pH of solutions. They proved very useful in the initial understanding of the physiological properties of dietary fibre, allowing a simple division into those which principally had effects on glucose and lipid absorption from the small intestine (soluble) and those which were slowly and incompletely fermented and had more pronounced effects on bowel habit (insoluble). However, the separation of soluble and insoluble fractions is not chemically very distinct being dependent on the conditions of extraction (18). Moreover, the physiological differences are not, in fact, so distinct with much insoluble fibre being rapidly and completely fermented while not all soluble fibre has effects on glucose and lipid

absorption.

Methodology for dietary carbohydrate analysis

Mono- and disaccharides

They can be analyzed specifically by enzymatic, gas-liquid chromatography (GLC) or high performance liquid chromatography (HPLC) methods. Depending on the food matrix to be analyzed, extraction of the low molecular weight carbohydrates in aqueous ethanol, usually 80% (v/v), may be advisable before analysis (5,6,7).

The enzymatic procedures are based on specific, highly purified enzymes and have been instrumental in providing means of specific and precise analysis of individual carbohydrates in mixtures without a large investment in instrumentation. Enzymatic methods are still preferable when one single carbohydrate is to be analyzed, e.g. glucose, as the end point of starch analysis.

When several different monosaccharides are to be determined simultaneously, HPLC or GLC methods are preferable. HPLC systems using sensitive amperometric detectors are gaining in popularity over GLC, in that the derivatization necessary before the GLC determination is avoided.

Polyols

Polyols are usually determined by GLC using alditol acetate derivatives. HPLC methods are also available.

Oligosaccharides

Oligosaccharides can also be determined by GLC or HPLC methods. These methods work well for purified preparations, but in complex foods or diets, enzymatic hydrolysis and determination of liberated monosaccharides is an alternative for specific determination. Malto-oligosaccharides are recovered as "starch" if not extracted before starch analysis.

Separation of oligosaccharides from polysaccharides

By definition, polysaccharides have 10 or more monomeric units, and Oligosaccharides less than 10. Analytically, separation is based on solubility in aqueous ethanol, usually around 80% (v/v). The alcohol solubility of carbohydrates, however, is dependent not only on the degree of polymerization (DP), but also on the molecular structure. For instance, highly branched carbohydrates may be soluble in 80% ethanol in spite of a DP considerably higher than 10. In practice, therefore, the separation of Oligosaccharides from polysaccharides is empirical and does not provide an exact division based on DP (18).

Starch

Quantitative analysis of starch in foods by most current methods is based on enzymatic degradation and specific determination of liberated glucose. Nutritionally, starch can be divided into glucogenic ("available") and resistant starch, which is not absorbed in the small intestine. Resistant starch is poorly

soluble in water and methods aiming at a total starch analysis employ an initial 2M potassium hydroxide (KOH) or dimethylsulfoxide solvent (DMSO) treatment to disperse crystalline starch fractions that would otherwise remain unhydrolyzed. Methods for measuring resistant starch are still in their infancy and have not yet been tested in formal collaborative studies. They aim at simulating normal starch digestion in the small intestine. A key step is to mimic the normal disintegration of the food which occurs during chewing. One method uses a standardized milling/homogenization technique (12), whereas others employ standardized chewing by volunteers (19,20). Both approaches have been evaluated against human ileostomy experiments with a limited number of food matrices (21).

Non-starch polysaccharides (NSP)

The determination of NSP is based on the following steps: (a) degradation of starch by enzymatic hydrolysis after solublization, (b) removal of low molecular weight carbohydrates, including starch hydrolysis products, (c) hydrolysis of the NSP to their constituent monomers, and (d) quantitative determination of those monomers. The acid hydrolysis step is a critical one, and it has to be designed as an optimal balance between complete hydrolysis and destruction of the liberated monomers (22,23).

The most widely-used method today for specific determination of the liberated monomers is GLC with alditol acetate derivatives. HPLC detection is an alternative gaining in popularity. Colourimetric determination is still preferred for uronic acids, which are derived mainly from pectic substances. A colourimetric method is also available for total NSP.

Fractions of NSP, such as cellulose and non-cellulosic polysaccharides, can be separated by using sequential extraction and hydrolysis methods. For instance, cellulose is not hydrolysed by dilute (1-2M) sulphuric acid, unless it has first been dispersed in concentrated acid.

Dietary fibre

Three methods for dietary fibre analysis have undergone extensive testing in recent years, including collaborative studies satisfactory enough for official approval of bodies such as the AOAC International (Association of Official Analytical Chemists) and the Bureau Communautaire de Reference (BCR) of the European Community (24):

1. The enzymatic, gravimetric AOAC methods of Prosky and co-workers, and subsequently Lee and co-workers.

2. The enzymatic-chemical methods of Englyst and co-workers.

3. The enzymatic-chemical method of Theander and co-workers (the Uppsala method).

The enzymatic-gravimetric AOAC methods are derived from methods aiming at simulating the digestion in the human small intestine to isolate an undigested residue as a measure of dietary fibre. This residue is corrected for associated ash and protein. Since no DMSO or KOH dispersion is used, starch that resists the amylases used in the assay will remain as a fibre component. Since the sample has to be milled, and since a heat-stable amylase (termamyl) is used at a

temperature close to 100°C, physically enclosed starch (RS_1) and resistant starch granules (RS_2) will not be included. Retrograded amylose (RS_3) that is included is the main form of resistant starch (RS) in processed foods. Lignin, a non-carbohydrate component of the dietary fibre complex is also included, as well as some tannins. These components are a very small proportion of most foods but can be substantial in some unconventional raw materials or special "fibre" preparations (25).

The Englyst method measures the NSP specifically, either as individual monomeric components by GLC (or HPLC) or colourimetrically as reducing substances (total NSP). Accordingly, DMSO is used initially to ensure a complete removal of starch, and lignin is not determined. The difference between estimates with the gravimetric methods and the Englyst method is mainly due to resistant starch and lignin (24).

The Uppsala method employs hydrolysis conditions and GLC determination of monomers in a similar way as in the Englyst method. However, DMSO is not employed for starch dispersion, and a gravimetric estimate of lignin (Klason lignin) is added to obtain the dietary fibre. The Uppsala method and the gravimetric AOAC methods give very concordant results (24).

Labelling

Food labelling has two main aims: to inform the consumer of the composition of the food and to assist them in the selection of a healthy diet. These two aims are not always easy to reconcile because the health benefit of different carbohydrate-containing foods cannot readily be communicated simply from a description of their composition.

Labelling should be based on the chemical classification used in Figure 1. Analytical methods should be clearly defined and validated. The principal information should be total carbohydrate, measured as the sum of the individual components. Further information on carbohydrate composition, based on the classification in Figure 1, could include terms such as sugars, starch and non-starch polysaccharides. Other terms, such as non-digestible oligosaccharides (NDO), polyols, resistant starch and dietary fibre may be used, provided the components included in these terms are clearly defined.

Availability and consumption

Trends in the supply and intake of carbohydrates can be studied by four principal approaches:

1. Production
2. Food balance sheets
3. Household surveys
4. Individual assessments

Food production statistics, which are available from FAO for every country in the world and for every crop, are useful for examining trends in consumption (26). From these data it can be seen that the major sources of carbohydrate in the human diet are:

1. Cereals
2. Root crops
3. Sugar crops
4. Pulses
5. Vegetables
6. Fruit
7. Milk products

Sustainability

Trends over the last 20-30 years indicate growth in world production of cereals, sugar cane, vegetables and fruit. On the other hand, production of root crops, pulses and sugar beet has changed little on a world basis. Marked decreases have actually been seen in pulse production in some countries in Asia, and in root crop production in Europe. This suggests a change in food preference away from roots and pulses and towards cereals. Examination of eating habits in a number of countries indicates that this is the case (27-29). Since root crops are an excellent source of carbohydrate, there is concern about this downward trend in production.

Populations continue to grow in most parts of the world and, overall, food production would seem to be keeping pace with population growth. Increased production is due to improved agricultural practices rather than increased crop area, the major reason for increases being greater use of fertilizer (30-32). There are, however, specific countries where this is not happening. For the entire continent of Africa, cereal production is inadequate.

A major question is how much more improvement and efficiency in production can be achieved, and whether the amount of carbohydrate will be sufficient for the world's population in the future. Projections for future growth suggest problems ahead, particularly in Africa (33).

Changing patterns of consumption

Both food balance information and results from individual assessments are used to determine carbohydrate intakes. Food balance data is intended to describe food available for consumption. It is unlikely to do so because it does not include home production, which is variable from country to country, and may be considerable in some developing countries (34,35). As a reflection of food consumed, food balance data is questionable, since it does not include food wasted or spoiled, or used for purposes other than human food, the proportion of which may change from year to year. As a result, food balance data for individual countries has failed to demonstrate the changes in consumption of carbohydrates which are seen using individual surveys (36-38).

Data from individual surveys also have limitations. Surveys are carried out by a variety of methodologies. While each has advantages and disadvantages, all suffer from a degree of underreporting. This can be intentional or involuntary, most likely due to individuals forgetting food items or not describing foods thought to be undesirable (35). There is also the failure to record data or the altering of actual diets. The difference, then, between food balance data and individual assessments, for energy and nutrient intakes, is not only the form of wastage and spoilage on the food balance side of the equation, but also the underreporting on the individual intake side. True food intakes therefore lie somewhere between food balance and individual intake estimates (35). Another major problem is the varied

carbohydrate terminology used in different countries. Many countries express total carbohydrate 'by difference', rather than as carbohydrate analyzed directly, and this results in overestimates of the percent energy derived from carbohydrate. There is also a great variety in terms used to describe simple sugars, such as "sugars", "sugar", "refined sugar", "added sugar", "sucrose", and "sugars minus lactose". Often there is no description of what is being reported (39). There is a need to standardize the terminology for carbohydrate and its components in individual surveys and a need for consistency in both reporting and the description of the terms used.

In spite of terminology difficulties, it is possible to gain a picture of carbohydrate intakes and trends. Annex 1 gives the intakes of carbohydrate and components where available, from a number of surveys since 1980. As a percent of energy, total carbohydrate ranges from about 40% to over 80%, with the developed countries, such as those in North America, Western Europe and Australia at the low end of the range, and developing countries in Asia and Africa at the high end. Starch accounts for 20%-50% or more of energy where the total carbohydrate intake is in the high range. Sugars account for 9%-27% of energy intake; where total carbohydrate is high, sugar intake is generally low. Where data are available, intake of carbohydrate as a percent of energy is higher for children than for adults.

Trends in consumption indicate a falling carbohydrate intake in developed countries until the last two decades (39). During that time some increase has been noted as fat intakes fall. The major sources of carbohydrate are cereals, representing over 50% of all carbohydrate consumed in both developed and developing countries, with sugar crops the next major source, followed by root crops, fruits, vegetables, pulses and milk products. In some of the developing countries much of the carbohydrate is derived from a single food source such as rice, cassava or maize. Carbohydrate foods are an important vehicle for protein, micronutrients and other food components, like phytochemicals, which have important benefits for health. Individual food sources vary, however, in the provision of these components. A single food source of carbohydrate is therefore undesirable and populations whose diets are primarily based on a single food can suffer from micronutrient deficiencies due to lack of variety. It is important, therefore, that a number of different carbohydrate sources be consumed and efforts should be made to encourage a wide variety of carbohydrate foods.

Data on intake of sources of sugars is only available for developed countries. These data show similar proportions of sugars are derived from cereal products, milk products and beverages, among these countries. There is some variation in the proportions derived from fruit and confectionery, with the UK consuming less fruit and higher amounts of confectionery than countries such as the United States and Australia (40-44).

Intakes of non-starch polysaccharides (45) range from about 19g/day in some countries in Europe and North America, to nearly 30g/day in rural Africa (46-48). Cereals are again the major source of this component. Data on intake of dietary fibre, determined by methods such as that of the AOAC (Association of Official Analytical Chemists) (49) and the older Southgate method (50), are about 15-20 g/day for North America, Europe and Australia, to 25-40 g/day for countries in Asia and Africa (47, 51-53).

Physiology

Carbohydrates have a wide range of physiological effects which may be important to health, such as:

- Provision of energy
- Effects on satiety/gastric emptying
- Control of blood glucose and insulin metabolism
- Protein glycosylation
- Cholesterol and triglyceride metabolism
- Bile acid dehydroxylation
- Fermentation

 Hydrogen/methane production
 Short-chain fatty acids production
 Control of colonic epithelial cell function

- Bowel habit/laxation/motor activity
- Effects on large bowel microflora

Carbohydrate as an energy source

Dietary carbohydrates have by convention been given an energy value of 4 kcal/g (17 kJ/g), although where carbohydrates are expressed as monosaccharides, the value of 3.75 kcal/g (15.7 kJ/g) is used. It is now clear, however, that a number of carbohydrates are only partly or not at all digested in the small intestine and are fermented in the large bowel to short chain fatty acids. These include the non-digestible oligosaccharides, resistant starch and non-starch polysaccharides. The process of fermentation is metabolically less efficient than absorption in the small intestine and these carbohydrates provide the body with less energy.

In light of a new understanding of the digestion and metabolism of carbohydrate and developments in methodology, the energy value of all carbohydrates in the diet should be reassessed and more accurate energy factors assigned to each group or sub-group. There are a number of potential approaches to accomplish this. These include the classic calorimetry experiments similar to those first undertaken by Atwater, as well as human balance studies and ileostomy recovery experiments. Knowledge of the chemistry of individual carbohydrates allows a prediction to be made regarding their digestion or fermentation, and an energy value to be assigned. *In vitro* models of fermentation can be constructed and from these the fermentation stoichiometry can be deduced. Studies using stable isotope tracer techniques may also be of value.

While the energy yield of carbohydrate delivered to the colon will vary according to the extent of colonic fermentation (or the assumptions made in the model used), there may be an argument for assigning a single energy value to all such carbohydrate. Published studies suggest that a caloric value of about 2 kcal/g (8

kJ/g) (54,55) would be a reasonable average figure for carbohydrate which reaches the colon. While individual carbohydrates will have different values, in the range of 1-2 kcal/g, these differences are unlikely to be of importance to health.

Satiety

The possibility of controlling hunger, satiety and food intake by altering the type of carbohydrate in food has intrigued a number of investigators (56). At present the variability of the findings and the lack of understanding of a clear relationship to physiologic parameters thought to be involved in the regulation of food intake limit practical application of this approach. It is unlikely that controlling a single dietary component, such as the type of sugar or starch, will lead to significant changes in the amount of food consumed. Also, compensation for small dietary changes made in one meal may often be seen at a subsequent meal. A better approach to controlling hunger and increasing satiety is likely to be associated with changes in the composition of the total diet (57).

Glucose and insulin

The digestion of dietary carbohydrates starts in the mouth, where salivary a-amylase initiates starch degradation. The starch fragments thus formed include maltose, some glucose and dextrins containing the 1,6-α -glycosidic branching points of amylopectin. The α -amylase degradation of starch is completed by the pancreatic amylase active in the small intestine.

Dietary disaccharides, as well as degradation products of starch, need to be broken down to monosaccharides in order to be absorbed. This final hydrolysis is accomplished by hydrolases attached to the intestinal brush-border membrane, referred to as "disaccharidases". Disaccharidase deficiencies occur as rare genetic defects, causing malabsorption and intolerance of the corresponding disaccharide.

Glucose and galactose are transported actively against a concentration gradient into the intestinal mucosal cells by a sodium dependent transporter (SGLT 1). Fructose undergoes facilitated transport by another mechanism (GLUT 5). Fructose taken together with other sugars (as in naturally fructose-containing foods) is better absorbed than fructose alone (58).

When delivered to the circulation, the absorbed carbohydrates cause an elevation of the blood glucose concentration. Fructose and galactose have to be converted to glucose mainly in the liver and therefore produce less pronounced blood glucose elevation. The extent and duration of the blood glucose rise after a meal is dependent upon the rate of absorption, which in turn depends upon factors such as gastric emptying as well as the rate of hydrolysis and diffusion of hydrolysis products in the small intestine.

Insulin is secreted as a response to blood glucose elevation but is modified by many neural and endocrine stimuli. Insulin secretion is also influenced by food related factors, especially by the amount and the amino acid composition of dietary proteins. Insulin has important regulatory functions in both carbohydrate and lipid metabolism and is necessary for glucose uptake by most body cells.

Lactose

Lactose, a β -linked disaccharide of glucose and galactose, is the principal sugar in milk. At birth, lactase activity is high in the brush-border of the small bowel of infants, but declines after weaning so that most populations of the world have low activity in adult life. The exceptions are Caucasian peoples and some other population groups in whom the majority retain a high lactase activity throughout life (59,60).

During the years since 1980, there has been a major change in the way lactose absorption is viewed and a resultant shift away from the concept that lactose "malabsorption" is a pathological state. Low mucosal lactase activity in adults is the norm throughout most of the world. However, such a state usually allows the drinking of modest quantities of milk spaced throughout the day without adverse symptoms. Milk consumption is therefore now being encouraged in many areas of the world because of its value as a source of protein, calcium and riboflavin. Fermented milk products, which have lower lactose content and contain enzymes and microorganisms that can assist in lactose digestion, are better tolerated than milk. Technology exists to reduce the lactose level in foods and this should be taken into consideration when milk is included as food aid. Cheese, however, has almost no lactose.

Lactose which is not digested, passes into the colon where it is fermented. In some individuals this causes lactose intolerance, the term used to describe the clinical symptoms of abdominal discomfort, flatulence and diarrhoea, associated with the ingestion of lactose containing foods by persons with low lactase activity. It also occurs as a transient phenomenon when the intestinal mucosa is injured following acute infection in children and in protein-energy malnutrition. It is also found in adults, particularly in association with coeliac disease and tropical sprue. In these conditions, lactose malabsorption is said to be "secondary" to intestinal mucosal disease. A small proportion of the Caucasian population also exhibits low lactase activity and lactose intolerance.

Protein glycosylation

The non-enzymatic glycation of proteins is dependent on the concentration of glucose and fructose in blood and the half-life of the protein. The initial reaction is between the monosaccharide and the amino group of an amino acid, usually lysine, to form a Shiff base which undergoes rearrangement and formation of Amadori products. As the reaction progresses, increasingly complex Maillard products are formed with the eventual production of Advanced Glycation End-products or AGEs which are associated with irreversible loss of protein function. The extent of glycation of specific proteins, such as Haemoglobin Ale in diabetics serves as an indication of medium term control of blood glucose. Examples of functional changes induced by glycation include lens proteins in the eye with resultant cataract formation, increased microvascular complications, abnormal fibrin network formation and impaired fibrinolysis. These changes are most clearly seen in diabetic patients (61,62).

Lipids and bile acids

There has been concern that a substantial increase in carbohydrate-containing food at the expense of fat, might result in a decrease in high-density lipoprotein and a corresponding increase in very low-density lipoprotein and triglycerides in the blood. However, there is no evidence that this happens when the increase in carbohydrates occurs as a result of increased consumption of vegetables, fruits

and appropriately processed cereals over prolonged periods.

Polysaccharides like oat β -glucan, guar gum and those from psyllium have been repeatedly shown to lower serum cholesterol levels in those with elevated levels, with little change if serum levels are normal (63,64). Proposed mechanisms include impaired bile acid and cholesterol reabsorption through physical entrapment in the small intestine, or inhibitory effects on cholesterol synthesis by products of lower bowel fermentation, particularly propionic acid. Not all fermentable polysaccharides are effective, however, and recent studies have indicated that neither oligosaccharides nor resistant starch have a significant effect on serum lipids in young normolipidemic subjects (21,65).

Fermentation

Fermentation is the colonic phase of the digestive process and describes the breakdown in the large intestine of carbohydrates not digested and absorbed in the upper gut. This process involves gut microflora and is unique to the colon of humans because it occurs without the availability of oxygen. It thus results in the formation of the gases hydrogen, methane and carbon dioxide, as well as short chain fatty acids (SCFA) (acetate, propionate and butyrate), and stimulates bacterial growth (biomass). The gases are either absorbed and excreted in breath, or passed out via the rectum. The major products of such fermentation are the SCFA which are rapidly absorbed and metabolized by the body. Acetate passes primarily into the blood and is taken up by liver, muscle and other tissues. Propionate is a major glucose precursor in ruminant animals such as the cow and sheep, but this is not an important pathway in humans. Butyrate is metabolized primarily by colonocytes and has been shown to regulate cell growth, and to induce differentiation and apoptosis (66).

Bowel habit

It has long been known that non-starch polysaccharides are the principal dietary component affecting laxation. This occurs through increases in bowel content bulk and a speeding up of intestinal transit time. The extent of the effect depends on the chemical and physical nature of the polysaccharides and the extent to which they are fermented in the colon. Fermentable polysaccharides stimulate increases in microbial biomass in the colon, resulting in some increase in fecal weight, but not to the extent of non-fermentable polysaccharides. The latter are not significantly degraded in the colon and become consituents of the stool. In so doing, they hold water and produce a marked increase in fecal weight. Similarly, resistant starch can increase fecal weight, but this again depends on the extent of fermentation (67).

Microflora

Carbohydrate which is fermented stimulates the growth of bacteria in the large gut. This is a generalized effect which leads to an increase in the total number of bacteria or biomass. When bacterial growth occurs, the microflora synthesize protein actively from preformed amino acids and peptides as well as some de-novo synthesis using ammonia as the source of nitrogen. The additional biomass is excreted in feces and is one of the mechanisms whereby carbohydrate influences bowel habit. The increased biomass excretion is accompanied by increased nitrogen excretion. The efficiency of conversion of carbohydrate to biomass is determined principally by the type of substrate, the rate of breakdown

and the transit time through the large intestine (68).

One of the more significant developments in recent years with regard to the gut microflora has been the demonstration that specific dietary carbohydrates selectively stimulate the growth of individual groups or species of bacteria. An example of this is the effect of fructo-oligosaccharides on the growth of bifidobacteria. The importance of bifidobacteria is that they may be one of the major contributors to colonization resistance in the colon, thereby protecting the host from invasion by pathogenic species. Foods which selectively stimulate the growth of gut bacteria are known as pre-biotics (69).





Chapter 2 - The role of carbohydrates in maintenance of health

Carbohydrates in the diet
Energy balance
Physical activity
Carbohydrate and behaviour
Carbohydrate through the life cycle

Carbohydrates in the diet

While the amount of carbohydrate required to avoid ketosis is very small (about 50 g/day), carbohydrate provides the majority of energy in the diets of most people. There are many reasons why this is desirable. In addition to providing easily available energy for oxidative metabolism, carbohydrate-containing foods are vehicles for important micronutrients and phytochemicals. Dietary carbohydrate is important to maintain glycemic homeostasis and for gastrointestinal integrity and function. Unlike fat and protein, high levels of dietary carbohydrate, provided it is obtained from a variety of sources, is not associated with adverse health effects. Finally, diets high in carbohydrate as compared to those high in fat, reduce the likelihood of developing obesity and its co-morbid conditions. An optimum diet should consist of at least 55% of total energy coming from carbohydrate obtained from a variety of food sources.

The consultation agreed that when carbohydrate consumption levels are at or above 75% of total energy there could be significant adverse effects on nutritional status by the exclusion of adequate quantities of protein, fat and other essential nutrients. In arriving at its recommendation of a minimum of 55% of total energy from carbohydrate, the consultation realised that a significant percentage of total energy needs to be provided by protein and fat, but that their contribution to total energy intakes will vary from one country to another on the basis of food consumption patterns and food availability.

Energy balance

In adults, it is important that the amount of energy ingested be matched to the amount of energy expended. Maintenance of energy balance is important in order to avoid obesity and its associated co-morbidities such as diabetes and cardiovascular disease. Positive energy balance and obesity occur when total energy intake exceeds total energy expenditure, regardless of composition of the excess energy. However, the composition of the diet can affect whether and to what extent positive energy balance occurs.

The composition of the diet can also affect the ability to maintain energy balance.

In particular, diets containing at least 55% of energy from a variety of carbohydrate sources, as compared to high fat diets, reduce the likelihood that body fat accumulation will occur. Substantial data suggest that diets high in fat content tend to promote consumption of more total energy than diets high in carbohydrates (58,70). This effect may be due to the low energy density of high carbohydrate diets, since total volume of food consumed appears to provide an important satiety cue (71). There are no data to suggest that different types of carbohydrates differentially affect total energy intake.

In addition to affecting the chance of having excess energy available, the composition of the diet also affects the proportion of excess energy that will be stored as body fat. The body has a large fat storage capacity and excess dietary fat is stored very efficiently in adipose tissue. Alternatively, the body's capacity to store carbohydrate is limited and excess carbohydrate is not efficiently stored as body fat (72). Instead, excess carbohydrate tends to be oxidized, leading to indirect fat accumulation via reductions in fat oxidation (73).

Excess fat and carbohydrate were previously thought to be equally fattening. This was due to the assumption that *de novo* lipogenesis was a commonly used pathway for disposal of excess carbohydrate. The available data suggest, however, that this process occurs rarely in human subjects and only in situations of appreciable carbohydrate overfeeding (74). In most usual circumstances, accumulation of body fat via *de novo* lipogenesis is quantitatively very low.

While noting the low overall contribution of *de novo* lipogenesis to body fat accumulation, it should be noted that *de novo* lipogenesis is increased with insulin resistance and with extremely high consumption of sucrose or fructose (74).

Physical activity

Maintenance of energy balance is dependent both on energy intake and energy expenditure. Maintaining regular physical activity greatly reduces the likelihood of creating positive energy balance, regardless of the composition of the diet. There is agreement that the combination of a high carbohydrate diet and regular physical activity is the optimal arrangement to avoid positive energy balance and obesity.

The increased energy needs of physical activity can be supplied by carbohydrate or fat. The importance of carbohydrate in the diet becomes more critical as the amount and intensity of physical activity increases.

In many developing countries, the major challenge is to meet daily energy needs created by high levels of daily physical labour. In such cases, any combination of carbohydrate and fat which provides sufficient energy is to be encouraged.

Many countries recommend increasing leisure time physical activity. While increased physical activity would clearly increase energy needs, these do not create needs for specific macronutrients. Rather, the optimum diet identified above is considered sufficient to provide for such physical activity.

There is substantial evidence that supplemental carbohydrate can improve performance for the elite endurance-trained athlete. A high carbohydrate diet during a few days preceding an endurance event, carbohydrate loading, a high carbohydrate pre-event meal and carbohydrate supplementation in the form of

carbohydrate-containing beverages have all been shown to enhance performance during long-distance cycling and running. There is, however, no evidence that such carbohydrate supplementation would improve performance for the majority of people who engage in recreational physical activity of lower intensity and duration. On the other hand, carbohydrate intake following exercise can help to quickly replenish depleted glycogen stores (75).

Carbohydrate and behaviour

It has been suggested that food intake could have important effects on behaviour. While providing breakfast to children who do not typically eat breakfast can increase cognitive performance (76), it is less clear that the overall composition of the diet can affect behaviour. It has been suggested that sugar consumption leads to hyperactivity in children. However, an extensive review of the literature in this area (77) concluded that there is no evidence to support the claim that refined sugar intake has any significant influence on either behaviour or" cognitive performance in children.

Because glucose is an essential fuel for the central nervous system, carbohydrate has also been suggested to play a role in memory and cognitive function. While there appears to be a relationship between glucose levels and memory processing, the clinical significance of this relationship remains unclear.

Carbohydrate through the life cycle

Energy and nutrient needs are increased in pregnancy and lactation, and the primary challenge for pregnant women is to meet these increased energy needs in order to ensure healthy offspring. It has been observed that where variety in the food supply is low and carbohydrate intake is high, a low birth weight is more common. This raises concerns about the adequacy of high carbohydrate diets to meet the energy and nutrient needs of pregnancy when food variety is limited. Energy and nutrient needs should be met by consumption of a wide variety of carbohydrate foods. There is also some concern about excessive fat intake in pregnancy since it may be associated with risk of obesity in the mother.

In many countries, infants receive 45-55% of energy from fat through breastmilk or formulas and 35-45% of energy from carbohydrate. While specific reductions in fat intake are not recommended below the age of two years, infants in many countries consume lower fat diets. This does not present a problem as long as energy requirements are fulfilled. From the age of two and on, the optimum diet (at least 55% of total energy from a variety of carbohydrate sources) should be gradually introduced.

During the first four to six months of life, exclusive breast feeding is recommended as this tailors the concentration of lactose to the maturing neonatal and infant gut, particularly while colonic microflora and pancreatic amylase production are developing. For infants fed on formula, the carbohydrate and other nutrient components should usually mimic breast milk to the extent possible and in accordance with standards of the Codex Alimentarius (78).

Carbohydrate digestion in the neonate and young infant is significantly influenced by both gastrointestinal maturation and the chemical nature of the carbohydrate ingested. The establishment of colonic microflora is responsible for colonic

carbohydrate scavenging, converting any carbohydrate entering the colon into short chain fatty acids. Any disturbances or inappropriate development of this microflora (incorrect infant formula, antibiotics, infection) leads to colonic carbohydrate overloading and diarrhoea.

Lactose from dairy products can be a major source of carbohydrate for young children. In addition, milk represents an excellent source of high quality protein, calcium, and riboflavin. In most populations, even those with low lactase activity, milk can be ingested in small amounts, especially after meals with dilution by co-ingestion. Fermented dairy products can be valuable items in the diet of most people irrespective of intestinal lactase status.

Often the transition from childhood to adulthood is associated with changes in dietary pattern. In developing countries, children frequently consume very high carbohydrate intakes from a single or a small number of sources, while adults have greater variety. In such cases, the adult diet is preferred. In developed countries, on the other hand, surveys indicate that children have higher intakes of carbohydrate from more sources than adults. In those countries, the diet consumed by children would seem to be more beneficial. In both situations, at least 55% of carbohydrate energy from a variety of sources is the optimum.

Individualization of carbohydrate intake is necessary for elderly populations. Elderly individuals in many countries are at risk as regards both malnutrition and obesity. Food intake patterns can be altered by changes in taste perception, chronic disease and medication use. While a high carbohydrate diet is recommended for prevention of weight gain and obesity, it should be recognized that some individuals may need diets higher in energy density (e.g. fats) in order to prevent malnutrition. Optimizing intake of carbohydrate to minimize glucose intolerance in later life is a consideration in countries where such intolerance is a problem.





Chapter 3 - Dietary carbohydrate and disease

Obesity
Non-insulin dependent diabetes mellitus (NIDDM)
Cardiovascular disease
Cancer
Gastrointestinal diseases other than cancer
Dental caries
Other conditions

Carbohydrates may directly influence human diseases by affecting physiological and metabolic processes, thereby reducing risk factors for the disease or the disease process itself. Carbohydrates may also have indirect effects on diseases, for example, by displacing other nutrients or facilitating increased intakes of a wide range of other substances frequently found in carbohydrate-containing foods. Evidence of associations between carbohydrates and diseases comes from epidemiological and clinical studies. There are relatively few examples in which direct causal links between carbohydrates and diseases have been proven. Thus the nutrient-disease or food-disease associations discussed below must be considered in terms of the strength of evidence from a range of observational studies and clinical experiments and the existence of plausible hypotheses.

Obesity

The frequency of obesity has increased dramatically in many developed and developing countries. This is of profound public health importance because of the clearly defined negative effect of obesity, especially when centrally distributed, in relation to diabetes, coronary heart disease and other chronic diseases of lifestyle. Genetic and environmental factors play a role in determining the propensity for obesity in populations and individuals. Lack of physical activity is believed to contribute to the increasing rates of obesity observed in many countries and may be a factor in whether an individual who is at risk will become overweight or obese.

High carbohydrate foods promote satiety in the short term. As fat is stored more efficiently than excess carbohydrate, use of high carbohydrate foods is likely to reduce the risk of obesity in the long term. Much controversy surrounds the extent to which sugars and starch promote obesity. There is no direct evidence to implicate either of these groups of carbohydrates in the etiology of obesity, based on data derived from studies in affluent societies. Nevertheless, it is important to reiterate that excess energy in any form will promote body fat accumulation and that excess consumption of low fat foods, while not as obesity-producing as excess consumption of high fat products, will lead to obesity if energy expenditure is not increased. While high carbohydrate diets may help reduce the risk of obesity by preventing overconsumption of energy, there is no evidence to suggest that the macronutrient composition of a low energy diet influences the rate and extent of

weight loss in the treatment of obese patients.

Non-insulin dependent diabetes mellitus (NIDDM)

High rates of NIDDM in all population groups are associated with rapid cultural changes in populations previously consuming traditional diets, and also with increasing obesity, especially when centrally distributed. Although the precise mode of inheritance has not been established, there is no doubt that genetic factors are involved. Certain populations appear to have a strong predisposition to the development of NIDDM to the extent that in some groups about half the adult population have the disease (79). Within all populations a family history of NIDDM is an important predisposing factor. Diet and lifestyle-related conditions which may lead to obesity will clearly influence the risk of developing NIDDM in populations and individuals who are susceptible to this condition. Foods rich in non-starch polysaccharides and carbohydrate-containing foods with a low glycemic index appear to protect against diabetes, the effect being independent of body mass index. In terms of disease prevention, it is not possible on the basis of current data to distinguish the relative merits of different types of non-starch polysaccharides. Some epidemiological evidence suggests particular benefit of appropriately processed cereal foods, while other epidemiological and clinical studies suggest benefits of non-starch polysaccharide from legumes and pectin-rich foods. Thus, avoiding obesity and increasing intakes of a wide range of foods rich in non-starch polysaccharide and carbohydrate-containing foods with a low glycemic index offers the best means of reducing the rapidly increasing rates of NIDDM in many countries.

Consuming a wide range of carbohydrate foods is now regarded as acceptable in the nutritional management of people who have already developed NIDDM. It has been suggested that between 60 and 70 per cent of total energy should be derived from a mix of mono-unsaturated fatty acids and carbohydrates. Carbohydrates should principally be derived from a wide range of appropriately processed cereals, vegetables and fruit, with particular emphasis on those foods which have a low glycemic index. The goal to achieve and maintain ideal body weight remains paramount, ensuring that foods high in fat which might predispose to obesity are not encouraged, even though they might have a low glycemic index.

Sucrose and other sugars have not been directly implicated in the etiology of diabetes and recommendations concerning intake relate primarily to the avoidance of all energy-dense foods in order to reduce obesity. Most recommendations for the management of diabetes permit modest (30-50 g/day) intakes of sucrose and other added sugars in the diabetic dietary prescription provided these are: a) consumed within the context of total energy allowance; b) nutrient-dense foods and foods rich in non-starch polysaccharides are not displaced; and, c) they are incorporated as part of a mixed meal. In some populations where fat intake is relatively low and sucrose intake high, a reduced intake of sucrose may be considered in the diabetic dietary prescription.

Increased meal frequency under iso-energetic conditions does not, in the long term, appear to be associated with any alteration in glycemic control. This suggests that personal preference is the key determinant of meal frequency, provided that body weight and daily (as well as long-term) glycemic control are not adversely influenced. Special diabetic food products are not generally recommended and fructose is not regarded as having any particular merits as a sweetener when compared with other added sugars. However, low-energy

beverages containing alternative non-nutritive sweeteners may be useful for people with diabetes.

Dietary factors have not been conclusively shown to be risk factors for insulin-dependent diabetes and the key advice concerning carbohydrates in the management of this condition concerns distribution of intake of carbohydrates during the day. Carbohydrate intake needs to be regularly distributed and balanced with injected insulin. The general principles of the diabetic dietary approach to non-insulin dependent diabetes may also be applied to those with insulin-dependent diabetes.

Cardiovascular disease

Many genetic and lifestyle factors are involved in the etiology of coronary heart disease and influence both the atherosclerotic and thrombotic processes underlying the clinical manifestations of this disease. Dietary factors may influence these processes directly or via a range of cardiovascular disease risk factors. Obesity, particularly when centrally distributed, is associated with an appreciable increase in the risk of coronary heart disease. There is also evidence implicating specific nutrients and, in particular, high intakes of some saturated fatty acids appear to be important promoters of coronary heart disease. On the other hand, there is increasing evidence of a strong protective effect by a range of antioxidant nutrients. Increasing carbohydrate intake can assist in the reduction of saturated fat and many fruits and vegetables rich in carbohydrates are also rich in several antioxidants. Cereal foods rich in non-starch polysaccharides have been shown to be protective against coronary heart disease in a series of prospective studies. There is no evidence for a causal role of sucrose in the etiology of coronary heart disease. The cornerstone of dietary advice aimed at reducing coronary heart disease risk is to increase the intake of carbohydrate-rich foods, especially cereals, vegetables and fruits rich in non-starch polysaccharide, at the expense of fat. Among those who are overweight or obese it is more important to reduce total fat intake and to encourage the consumption of the most appropriate carbohydrate-containing foods. There has been concern that a substantial increase in carbohydrate-containing food at the expense of fat, might result in a decrease in high-density lipoprotein and an increase in very low-density lipoprotein and triglycerides in the blood. There is, however, no evidence that this occurs when the increase in carbohydrates results from increased consumption of vegetables, fruits and appropriately processed cereals, over prolonged periods.

Certain non-starch polysaccharides (for example β -glucans) have been shown to have an appreciable effect in lowering serum cholesterol when consumed in naturally occurring foods, or foods which have been enriched by purified forms, or even when fed as dietary supplements. Such polysaccharides may be used in the management of patients with existing hypercholesterolemia but their role, if any, in the prevention of coronary heart disease remains to be established.

Less information is available concerning the role of carbohydrates in other cardiovascular diseases. Plant foods are good sources of potassium and reducing the sodium to potassium ratio may help to reduce the risk of hypertension. Limited data suggest a protective effect of vegetables and fruit in cerebrovascular disease.

There has been considerable debate in many developed countries which have high rates of coronary heart disease regarding the age at which children should start to reduce fat intake towards the recommended level for adults. Clearly

children require an adequate intake of energy for growth, and it is important that this does not include an excessive intake of carbohydrates at a very young age. It is generally accepted that dietary carbohydrate should gradually be increased and fat reduced after the age of two years, so that by the age of five years children should have reached a diet in the range of that recommended for adults. This advice should, of course, include the key dietary guidelines for children and adolescents, which suggest that nutritional adequacy should be achieved by eating a wide variety of foods and that energy intake should be adequate to promote growth and development, and to reach and maintain desirable body weight.

Cancer

Diet is widely regarded as important in the etiology of colorectal cancer with meat and fat considered the primary risk factors, and fruit, vegetable and cereal foods considered to be protective. Cancer is a disease associated with well-recognized genetic abnormalities and for colorectal cancer in particular, defects in a number of genes have been clearly defined (67,80). These genes mostly code for proteins responsible for the control of either cell growth, cell-to-cell communication or DNA repair. They are mainly oncogenes or tumor suppressor genes. For the development of colorectal cancer an individual must acquire several of these genetic abnormalities in the same cell. The acquisition of gene defects in somatic cells is thought to be through DNA damage and a resultant failure of the DNA repair system (or of apoptosis). Dietary carbohydrate is thought to be protective through mechanisms involving arrest of cell growth, differentiation and selection of damaged cells for cell death (apoptosis). This is probably achieved primarily through the action of butyric acid which is formed in the colon from fermentation of carbohydrates such as resistant starch and non-starch polysaccharides. Such carbohydrates are found mostly in cereals, fruit and vegetables.

The process of fermentation may protect the colorectal area against the genetic damage that leads to colorectal cancer through other mechanisms which include: a) the dilution of potential carcinogens; b) the reduction of products of protein fermentation through stimulation of bacterial growth; c) pH effects; d) maintenance of the gut mucosal barrier; and, e) effects on bile acid degradation. These mechanisms, however, are much less well-established.

Carbohydrate staple foods are a source of phytoestrogens which may be protective for breast cancer. Cancer risk is increased for the obese. This applies especially to cancers of the breast and uterus. However, this is a general effect of total energy intake and not specifically of carbohydrates. Dietary carbohydrates do not have a known role in the etiology of lung, breast, stomach, prostate, pancreas, oesophagus, liver or cervical cancers. There is, however, some evidence that there is an increased risk of ovarian cancer in women with mild galactosemia (81,82).

Gastrointestinal diseases other than cancer

Intakes of non-starch polysaccharides and resistant starch are the most important contributors to stool weight. Therefore, increasing consumption of foods rich in these carbohydrates is a very effective means of preventing and treating constipation, as well as haemorrhoids and anal fissures. Bran and other cereal sources containing non-starch polysaccharide also appear to protect against diverticular disease and have an important role in the treatment of this condition. Obesity is an important risk factor for gallstones. High intakes of carbohydrate may

facilitate the colonization of bifidobacteria and lactobacilli in the gut and thus reduce the risk of acute infective gastrointestinal illnesses.

Dental caries

The incidence of dental caries is influenced by a number of factors. Foods containing sugars or starch may be easily broken down by a-amylase and bacteria in the mouth and can produce acid which increases the risk of caries. Starches with a high glycemic index produce more pronounced changes in plaque pH than low glycemic index starch, especially when combined with sugars (20). However, the impact of these carbohydrates on caries is dependent on the type of food, frequency of consumption, degree of oral hygiene performed, availability of fluoride, salivary function, and genetic factors. Prevention programmes to control and eliminate dental caries should focus on fluoridation and adequate oral hygiene, and not on sucrose intake alone.

Other conditions

There are a number of inherited conditions having significant implications for restricted dietary carbohydrate intake in infants and children. These include rare conditions such as galactosemia, fructose intolerance, a wide range of glycogen storage diseases, sucrose deficiencies and monosaccharide transport deficiencies. Though rare in incidence, their early detection and careful dietary management is important if severe handicap or pathology is to be avoided.





Chapter 4 - The role of the glycemic index in food choice

Definition of glycemic index (GI)
Factors influencing the blood glucose responses of foods
Calculation of glycemic index of meals or diets
Practical application of the glycemic index
Physiologic and therapeutic effects of low glycemic index foods

Carbohydrate foods often contain vitamins and minerals plus other compounds, such as phytochemicals and antioxidants, which may have health implications. Consuming a wide variety of carbohydrate foods is therefore recommended as this is more likely to be a nutritionally adequate diet with the health benefits commonly ascribed to carbohydrate foods (83).

Food choice depends not only on nutrition and health considerations but also on factors such as local availability, cultural acceptability and individual likes and needs. There is no one measure which can be used to guide food choices in all cases. The chemical composition of foods (e.g. fat, sugars, dietary fibre content) should be an important factor influencing food choice. However, simply knowing the chemical nature of the carbohydrates in foods, for example, does not reliably indicate their actual physiologic effects. Foods which are good choices in some situations may not be the best choices in others. Likewise, foods which are poor choices in some situations may be good choices in others.

Two indices of carbohydrate foods based on their physiologic functions have been proposed. A recently suggested satiety index (84) measures the satiety value of equal energy portions of foods relative to a standard, which is white bread. The factors which control food intake are complex and satiety needs to be distinguished from satiation. Nevertheless, investigation of satiety indices of foods is considered an interesting area of future research, which, if validated, may aid in the selection of appropriate carbohydrate foods to promote energy balance. A more established index is the glycemic index which can be used to classify foods based on their blood glucose raising potential.

Definition of glycemic index (GI)

The glycemic index is defined as the *incremental area* under the *blood glucose* response curve of a *50g carbohydrate portion* of a test food expressed as a percent of the response to the same amount of carbohydrate from a *standard food* taken by the *same subject.* The italicized terms are discussed below because the methods used to determine the glycemic index of foods and to apply the information to diets may profoundly affect the results obtained.

Incremental area under the curve

A number of different methods have been used to calculate the area under the curve. For most glycemic index data, the area under the curve has been calculated as the incremental area under the blood glucose response curve (IAUC), ignoring the area beneath the fasting concentration. This can be calculated geometrically by applying the trapezoid rule. When a blood glucose value falls below the baseline, only the area above the fasting level is included. Sample data are shown in Table 1. The data for Standard #1 are used in the diagram in Figure 2 to illustrate the details of the actual calculation.

TABLE 1 Sample blood glucose responses to the ingestion of 50g carbohydrate

Minutes	0	15	30	45	60	90	120	IAUC
Standard #1	4.3	6.3	7.9	5.3	4.1	4.6	4.9	114
Standard #2	4.0	6.0	6.7	5.5	5.3	5.0	4.2	155
Standard #3	4.1	5.8	8.0	6.5	5.9	4.8	3.9	179
Test Food	4.0	5.0	5.8	5.4	4.8	4.2	4.4	93

50g carbohydrate portion:

The portion of food tested should contain 50g of glycemic (available) carbohydrate. In practice, glycemic carbohydrate is often measured as total carbohydrate minus dietary fibre, as determined by the AOAC method. Since this method does not include RS 1 and RS2 when they are present, they will be mistakenly included as glycemic carbohydrate.

Blood glucose response

This is normally measured in capillary whole blood. Plasma glucose can be used to determine the glycemic index and gives similar values. However, capillary blood is preferred because it is easier to obtain, the rise in blood glucose is greater than in venous plasma and the results for capillary blood glucose are less variable than those for venous plasma glucose. Thus, differences between foods are larger and easier to detect statistically using capillary blood glucose (85). An illustration of the difference between glucose as measured in simultaneously-obtained venous plasma and capillary whole blood is shown in Table 2.

TABLE 2 Glucose response from capillary blood and venous plasma

	0 min	15 min	30 min	45 min	60 min	90 min	120 min	IAUC
Capillary blood	4.1	6.3	9.0	8.7	6.7	5.7	3.9	279
Venous plasma	5.0	7.1	8.8	8.0	5.6	5.4	4.2	155

Standard food

Either white bread or glucose can be used as the standard food. The GI values obtained if white bread is used are about 1.4 times those obtained if glucose is the standard food. Other standard foods could be used, but to enable comparison with data in the literature, the GI of the new standard food relative to standardized white

bread or glucose should be established.

Same subject

Blood glucose responses vary considerably from day-to-day within subjects. Thus, to obtain a representative mean response to the standard food, it is recommended that the standard food be repeated at least three times in each subject. This is illustrated by the data in Table 1, which is typical for normal subjects. The standard food was repeated three times giving IAUCs of: 114, 155 and 179. The mean ± SD IAUC is 149 ± 33 and the coefficient of variation (100 × SD/mean) is 22%. For this subject, the GI of the test food = 100 × 93/149 = 62.

Figure 2 - Sample calculations of incremental area under the curve (IAUC)

The IAUC for the data illustrated above (Standard #1, Table 3) equals the sum of the areas of the triangles and trapezoids: A+B+C+D+F

The area of triangle A = 2.0 × 15/2 = 15.0
The area of trapezoid B = (2.0 + 3.6) × 15/2 = 42.0
The area of trapezoid C = (3.6 + 1.0) × 15/2 = 34.5
The area of triangle D = 1.0 × t72

since: t'/15=1.0/(1.0+0.2)
therefore: t' = 15 × 1.0/1.2 = 12.5
therefore the area of triangle D = 1.0 × 12.5/2 = 6.25

The area of triangle E = 0.3 × t''/2

since: t''/30 = 0.3/(0.3 + 0.2)
therefore: t'' = 30 × 0.3/0.5 = 18
therefore the area of triangle D = 0.3 × 18/2 = 2.7

The area of trapezoid F = (0.3 + 0.6) × 30/2 = 13.5
Therefore, IAUC = 15.0 + 42.0 + 34.5 + 6.25 + 2.7 +13.5 = 114 mmol.min/L

Protocol

To determine the GI of the food, the tests illustrated in Table 1 would be repeated in six more subjects and the resulting GI values averaged. Normally, the GI for more than one food would be determined in one series of tests, for example, each subject might test four foods once each and the standard food three times for a total of seven tests in random order on separate days. Subjects are studied on separate days in the morning after a 10-12 ho overnight fast. A standard drink of water, tea or coffee should be given with each test meal.

Factors influencing the blood glucose responses of foods

Starchy foods with a low GI are digested and absorbed more slowly than foods with a high GI. Some factors that influence glycemic properties of foods are listed in Table 3.

TABLE 3 Food factors influencing glycemic responses

Amount of carbohydrate
Nature of the monosaccharide components
Glucose
Fructose
Galactose
Nature of the starch
Amylose
Amylopectin
Starch-nutrient interaction
Resistant starch
Cooking/food processing
Degree of starch gelatinization
Particle size
Food form
Cellular structure
Other food components
Fat and protein
Dietary fibre
Antinutrients
Organic acids

Calculation of glycemic index of meals or diets

The GI can be applied in a detailed fashion to mixed meals or whole diets by calculating the weighted GI value of the meal or diet. For example, the way to calculate the GI of a meal containing bread, cereal, sucrose, milk and orange juice is shown in Table 4.

TABLE 4 Calculation of the glycemic index of meals

Food	Grams Glycemic Carbohydrate	Proportion of total Glycemic Carbohydrate	Food Glycemic Index	Meal Glycemic Index *
Bread	25	0.342	100	34.2
Cereal	25	0.342	72	24.6
Milk	6	0.082	39	3.2
Sucrose	5	0.068	87	5.9
Orange juice	12	0.164	74	12.1
TOTAL	73			**80.0**

* Values for each food equals the proportion of total glycemic carbohydrate multiplied by the food GI. The sum of these values is the meal GI.

Using this type of calculation, there is a good correlation between meal GI and the

observed glycemic responses of meals of equal nutrient composition. Blood glucose responses are also influenced by the amount of carbohydrate in the meal. To compare the expected glycemic load of meals with different carbohydrate contents, a non-linear adjustment can be applied (86), but this has only been tested in normal subjects.

For detailed application of the GI, a value of the GI for every food in the diet or meal needs to have been assigned (for many foods the value has to be estimated). The accuracy of the calculation depends upon the accuracy of the GI values ascribed to foods, which may vary from place to place due to local factors such as variety, cooking, processing, etc. Foods particularly prone to such variation include rice, potatoes and bananas.

Practical application of the glycemic index

The glycemic index can be used, in conjunction with information about food composition, to guide food choices. For practical application, the glycemic index is useful to rank foods by developing exchange lists of categories of low glycemic index foods, such as legumes, pearled barley, lightly refined grains (e.g. whole grain pumpernickel bread, or breads made from coarse flour), pasta, etc. Specific local foods should be included in such lists where information is available (e.g. green bananas in the Caribbean and specific rice varieties in Southeast Asia).

In choosing carbohydrate foods, both glycemic index and food composition must be considered. Some low GI foods may not always be a good choice because they are high in fat. Conversely, some high GI foods may be a good choice because of convenience or because they have low energy and high nutrient content. It is not necessary or desirable to exclude or avoid all high GI foods.

Physiologic and therapeutic effects of low glycemic index foods

Meals containing low GI foods reduce both postprandial blood glucose and insulin responses. Animal studies suggest that incorporating slowly digested starch into the diet delays the onset of insulin resistance. Some epidemiologic studies suggest that a low GI diet is associated with reduced risk of developing non-insulin diabetes in men (87) and women (88). Clinical trials in normal, diabetic and hyperlipidemic subjects show that low GI diets reduce mean blood glucose concentrations, reduce insulin secretion and reduce serum triglycerides in individuals with hypertriglyceridemia (89,90,91,92). In addition, the digestibility of the carbohydrate in low GI foods is generally less than that of high GI foods. Thus, low GI foods increase the amount of carbohydrate entering the colon and increase colonic fermentation and short chain fatty acid production. This has implications for systemic nitrogen and lipid metabolism, and for local events within the colon.



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Chapter 5 - Goals and guidelines for carbohydrate food choices

Rationale and framework
Principles of carbohydrate food choices
Carbohydrate nutrient and food goals
Translation from carbohydrate nutrients to foods
Considerations for target audiences

Rationale and framework

Although the scientific basis for dietary guidelines requires an understanding of physiology and health relationships, the guidance most helpful to consumers uses food-based terms (93). In preparing such guidelines, food traditions and beliefs must be taken into account and the total food intake should reflect practical issues, such as meal patterns, food status, celebratory or usual role, seasonal availability, affordability and sustainability. These, including the health priorities, are matters for national policy makers.

Principles of carbohydrate food choices

The principles are:

1. To acknowledge the socio-cultural context, lifestyle and stage of life-cycle, in food carbohydrate choice;

2. To give preference to food choices rather than to nutrient goals in carbohydrate food choices, and in so doing:

 a. Use food categories as a guide to chemically defined carbohydrate type.

 b. Use numbers of portions (serving sizes) of foods from designated food categories in order to provide semi-quantitative food-based advice. This may imply that meal frequency would need to increase in some cultures, because the accommodation of enough carbohydrate food in the course of the day, without an excessive amount on any one occasion, requires more frequent servings and consumption;

3. To appreciate that many of the world's health problems are associated with inadequate carbohydrate intake, and potentially also

associated with inappropriate carbohydrate intake;

4. To ensure the acceptability and practicality of any recommended change in carbohydrate food intake;

5. To acknowledge that there may be unintended consequences involved in carbohydrate food intake change, and also to ensure that risks involved in dietary changes from traditional diets is considered;

6. To monitor the intake of carbohydrate foods and, wherever possible, of chemically defined carbohydrate components of those foods in relation to health issues.

7. To ascertain whether food carbohydrate choices encourage biodiversity and are sustainable.

Carbohydrate nutrient and food goals

Nutrient goals

The minimum amount of carbohydrate in the human diet that is needed to avoid ketosis is of the order of 50 g/day in adults. Beyond this, additional energy needs are best met by nutrient-dense carbohydrate foods. There must, of course, be adequate intakes of protein (with essential amino acids) and essential fatty acids from fat. Moderate intake of sugar-rich foods can also provide for a palatable and nutritious diet.

Food goals

There are a number of approaches to translating nutrient recommendations to food goals:

1. Recommending the total weight of food groups to be consumed. Various national food guides have suggested quantities of specific foods to be consumed, such as fruits and vegetables, and pulses, nuts and seeds.

2. Examining sources of carbohydrate foods in various diets, particularly diets which have desirable total carbohydrate intakes or from countries where the incidence of lifestyle diseases is low. Recommendations can then be made on the basis of intakes.

3. Examining major food groups which contain carbohydrate foods and recommending numbers of servings of those food groups. Numerous countries around the world, both developed and developing, have produced food guides with such groupings, and considering the level of agreement that exists for carbohydrate as a percent energy, these food guides are remarkably consistent in their advice.

4. Examining indices which exist to describe various physiological properties of carbohydrate-containing foods, such as glycemic index values and values from other indices which are presently being

developed.

On the basis of the above approaches, and taking into account the principles for carbohydrate food choice, the following recommendations can be made:

1. A variety of foods should provide the carbohydrate in the diet, not a single or small number of sources.

2. Cereals, roots, pulses, fruit and vegetables are all components of a healthy diet throughout the world.

3. Cereal foods or root crops, where this is the main staple, should provide the major source of carbohydrate energy.

4. Intake of fruits and vegetables (including potatoes in developed countries) should be high. As well as being a valuable source of carbohydrate, fruit and vegetables are an important source of antioxidant vitamins and other food components.

5. Consumption of pulses, nuts and seeds should be encouraged. While this group often represents only a small amount of carbohydrate energy, these foods are a good source of protein and micronutrients. They should be consumed with cereals to optimize protein quality.

6. At least small quantities of milk products are desirable, even when low lactase activity exists, since these are a good source of protein and micronutrients.

These recommendations apply to all individuals over the age of two years, with adjustments as necessary for growth and the increased demand of pregnancy and lactation.

Translation from carbohydrate nutrients to foods

Achieving goals for intake of carbohydrates does not ensure nutritional adequacy. Carbohydrate foods provide a range of nutrients and other substances essential for health in addition to energy. It is therefore essential to consume a variety of foods in order to derive the full benefits of a high carbohydrate diet. Nutrients from foods require monitoring. For example, in Iran (94) carbohydrate foods include vegetables (250 g/day), fruits (210 g/day), pulses (20 g/day) and cereals (wheat at about 250 g/day and rice 110 g/day, uncooked). Wheat has mostly been consumed as bread with traditional pastries being festive foods. Recently, consumption of the latter has increased substantially with potential reduction of nutritionally useful food groups traditionally accompanying bread. This may not significantly impact on total carbohydrate intake, but could influence nutritional adequacy. Traditional methods of food preparation and preservation facilitate food choice variety, and promote nutritional benefits. Alteration of traditional practices may compromise such benefits. Ongoing monitoring may be required to guard against nutritional inadequacy.

Considerations for target audiences

Planners and policy makers need to:

1. Recognize dietary goals of at least 55% of total energy from a variety of carbohydrate sources.

2. Recognize the extent of change necessary in order to meet these goals (e.g. it may take considerable change in food production and consumption to meet goals in Western countries).

3. Understand that there must be a gradual transition in meeting new dietary guidelines and that new terminology will need to be gradually accepted.

4. Consider the effects of economic and cultural factors in achieving dietary goals.

5. Develop clear guides about the types and quantities of food recommended.

6. Develop methods to monitor food consumption to meet dietary goals.

Primary producers and processors need to:

1. Consider how existing and new technologies can be used to help meet dietary goals regarding the quantity and nutritional properties of food carbohydrates, as well as levels of micronutrients and other desirable food components.

2. Provide foods, such as breakfast cereals and snack foods that are high in NSP, low in energy density, and with a low glycemic index.

3. Increase the availability and convenience of fruits and vegetables.

4. Provide appropriate information to the consumer on food labels.

To facilitate individual choice

Provide easily understandable food-based guides for the consumer.





Chapter 6 - Recommendations

The following recommendations are derived from the Consultation discussions and resulting conclusions detailed in the report. Specific recommendations are grouped under the appropriate report headings.

The role of carbohydrates in nutrition

The Consultation RECOMMENDS:

1. That the terminology used to describe dietary carbohydrate be standardized with carbohydrates classified primarily by molecular size (degree of polymerization or DP) into sugars (DP 1-2), oligosaccharides (DP 3-9) and polysaccharides (DP 10+). Further subdivision can be made on the basis of monosaccharide composition. Nutritional groupings can then be made on the basis of physiological properties.

2. That the concept of glycemic carbohydrate, meaning "providing carbohydrate for metabolism" be adopted.

3. Against the use of the terms extrinsic and intrinsic sugars, complex carbohydrate and available and unavailable carbohydrate.

4. That food laboratories measure total carbohydrate in the diet as the sum of the individual carbohydrates and not "by difference".

5. That the use of the term dietary fibre should always be qualified by a statement itemizing those carbohydrates and other substances intended for inclusion. Dietary fibre is a nutritional concept, not an exact description of a component of the diet.

6. That the use of the terms soluble and insoluble dietary fibre be gradually phased out. The Consultation recognized that these terms are presently used but does not consider them a useful division either analytically or physiologically

7. That the analysis and labelling of dietary carbohydrate, for whatever purpose, be based on the chemical divisions recommended. Additional groupings such as polyols, resistant starch, non-digestible oligosaccharides and dietary fibre can be used, provided the included components are clearly defined.

8. That the energy value of all carbohydrate in the diet be reassessed using modern nutritional and other techniques. However, for carbohydrates which reach the colon, the Consultation recommends that the energy value be set at 2 kcal/g (8 kJ/g) for nutritional and labelling purposes.

9. That the continued production and consumption of root crops and pulses be encouraged to ensure the adequacy and diversity of the supply of carbohydrate.

10. That the continued consumption of traditional foods rich in carbohydrate should

be encouraged where populations are in transition from a subsistence rural economy to more prosperous urban lifestyles. Processed foods are likely to be a substantial part of the diet and processing can be used to optimize nutritional properties.

The role of carbohydrates in the maintenance of health

The Consultation RECOMMENDS:

11. That the many health benefits of dietary carbohydrates should be recognized and promoted. Carbohydrate foods provide more than energy alone.

12. An optimum diet of at least 55% of total energy from a variety of carbohydrate sources for all ages except for children under the age of two. Fat should not be specifically restricted below the age of 2 years. The optimum diet should be gradually introduced beginning at 2 years of age.

13. That energy balance be maintained by consuming a diet containing at least 55% total energy from carbohydrate from various sources and engaging in regular physical activity.

14. Against consuming carbohydrate levels above the optimum, including carbohydrate-containing beverages, for purposes of recreational physical activity. Higher carbohydrate intakes are only needed for long-term extreme endurance physical activities.

15. That, as a general rule, a nutrient-dense, high carbohydrate diet be considered optimal for the elderly, but that individualization is recommended because their specific nutritional needs are complex.

Dietary carbohydrate and disease

The Consultation RECOMMENDS:

16. That a wide range of carbohydrate-containing foods be consumed so that the diet is sufficient in essential nutrients as well as total energy, especially when carbohydrate intake is high.

17. That the bulk of carbohydrate-containing foods consumed be those rich in non-starch polysaccharides and with a low glycemic index. Appropriately processed cereals, vegetables, legumes, and fruits are particularly good food choices.

18. That excess energy intake in any form will cause body fat accumulation, so that excess consumption of low fat foods, while not as obesity-producing as excess consumption of high fat products, will lead to obesity if energy expenditure is not increased. Excessive intakes of sugars which compromise micronutrient density should be avoided. There is no evidence of a direct involvement of sucrose, other sugars and starch in the etiology of lifestyle-related diseases.

19. That national governments provide populations in transition from traditional diets to those characteristic of developed countries, with dietary recommendations to ensure nutritional adequacy and retention of an appropriate balance of macronutrients.

The role of glycemic index in food choice

The Consultation RECOMMENDS:

20. That for healthy food choices, both the chemical composition and physiologic effects of food carbohydrates be considered, because the chemical nature of the carbohydrates in foods does not completely describe their physiological effects.

21. That, in making food choices, the glycemic index be used as a useful indicator of the impact of foods on the integrated response of blood glucose. Clinical application includes diabetes and impaired glucose tolerance. It is recommended that the glycemic index be used to compare foods of similar composition within food groups.

22. That published glycemic response data be supplemented where possible with tests of local foods as normally prepared, because of the important effects that food variety and cooking can have on glycemic responses.





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